FORM PTO-1390
(REV. 1-98)

U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

63 Rec'd PCT/PTO 08 DEC 1998

ATTORNEY'S DOCKET NUMBER
2565-136P

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)
NEW
09/202070

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/JP97/01442	April 24, 1997	None

TITLE OF INVENTION
FILM ACOUSTIC WAVE DEVICE AND ITS MANUFACTURING METHOD AND CIRCUIT DEVICE

APPLICANT(S) FOR DO/EO/US
WADAKA, Shusou; MISU, Koichiro; NAGATSUKA, Tsutomu; KIMURA, Tomonori; KAMEYAMA, Shumpei

Applicant herewith submits to the Untied States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39 (1).
4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(3)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(2)).
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98., 1449- W/9 References and International Search Report
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
    ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information:
    1.) Co-Pending Letter
    2.) Thirty-three (33) sheets of Formal Drawings

U.S. APPLICATION NO (if known, see 37 CFR 1 5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
NEW	PCT/JP97/01442	2565-136P

17. ☒ The following fees are submitted:

	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492(a)(1)-(5): Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO............ **$970.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO........ **$930.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO............ **$760.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)............ **$670.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4)................ **$96.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 930.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total Claims	23 - 20 =	3	X $18.00	$ 54.00	
Independent Claims	3 - 3 =	0	X $78.00	$ 0	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)		No	+ $260.00	$ 0	
TOTAL OF ABOVE CALCULATIONS =				$ 984.00	
Reduction of ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28).				$	
SUBTOTAL =				$ 984.00	
Processing fee of **$130.00** for furnishing the English translation later than ☐20 ☐30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$	
TOTAL NATIONAL FEE =				$ 984.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$ 40.00	
TOTAL FEES ENCLOSED =				$ 1024.00	
				Amount to be: refunded	$
				charged	$

a. ☒ A check in the amount of $ 1024.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account. No. __________ in the amount of $______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 02-2448.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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SIGNATURE

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REGISTRATION NUMBER

/dlg December 8, 1998

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IN THE U.S. PATENT AND TRADEMARK OFFICE

APPLICANTS: WADAKA, Shusou

INT'L. APPLN. NO.: PCT/JP97/01442

SERIAL NO.: NEW GROUP:

FILED: December 08, 1998 EXAMINER:

FOR: FILM ACOUSTIC WAVE DEVICE AND ITS MANUFACTURING METHOD AND CIRCUIT DEVICE

PRELIMINARY AMENDMENT

BOX PATENT APPLICATION
Assistant Commissioner of Patents
and Trademarks
Washington, D.C. 20231

December 08, 1998

Sir:

The following Preliminary Amendments and Remarks are respectfully submitted in connection with the above-identified application.

IN THE SPECIFICATION:

Before line 1, insert --This application is the national phase under 35 U.S.C. §371 of prior PCT International Application No. PCT/JP97/01442 which has an International filing date of April 24, 1997 which designated the United States of America.--

PAGE 29: Line 22, after components, please insert -- such as stray capacitance, stray inductance and resistance--

PAGE 31: Line 22, please change "electrode" to --non-electrode--

REMARKS

The specification has been amended to provide a cross-reference to the previously filed International Application.

The amendments to the specification are merely to correct minor typographical errors and to place the application into better form prior to examination.

If necessary, the Commissioner is hereby authorized in this, concurrent, and future replies, to charge payment or credit any overpayment to Deposit Account No. 02-2448 for any additional fees required under 37 C.F.R. §1.16 or under 37 C.F.R. §1.17; particularly, extension of time fees.

Respectfully submitted,

BIRCH, STEWART, KOLASCH & BIRCH, LLP

By

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SPECIFICATION

Film acoustic wave device and its manufacturing method and Circuit Device.

Field of the invention

The invention relates to a film acoustic wave device such as filter and resonator that utilizes acoustic waves, and a manufacturing method of the film acoustic wave device.

Background of the invention

Using a conversion process from electric signals to acoustic waves for a piezoelectric material, the film acoustic wave device functions as a filter or a resonator.

Figs.34, 35, 36 and 37 are examples of conventional film acoustic wave devices of this type as disclosed in the Japanese examined patent publication "sho61-269410" (hereinafter document 1).

Fig.34 is a configuration of the conventional bulk acoustic wave device of this type.

Fig.35 is a cross-section cut through A-A of Fig.34.

A description of the numbered components indicated in the figures follows: a glass substrate 1; a piezoelectric thin film 2 made of zinc oxide (ZnO); an interdigital transducer of input side 3; and an interdigital transducer of output side 4; electrode fingers 5; and opposing electrodes 6 made of aluminum (Al).

Figs.36 and 37 are graphs that show properties of this type of conventional film acoustic wave device of Figs.34 and 35. Fig.36 shows a relationship between an acoustic velocity Vs and a normalized thickness of thin film kh. Fig.37 shows a relationship of an electromechanical coupling constant K^2 and the normalized thickness of thin film.

Figs.38, 39 and 40 are examples of the conventional film acoustic wave devices of this type as disclosed in the Japanese unexamined patent publication "sho63-18708" (hereinafter document 2).

Figs.38 is a cross-section similar to Fig.35.

Fig.39 shows a relationship between the acoustic velocity Vs and the normalized thickness of thin film for the conventional film acoustic wave device of Fig.38. Fig.40 shows a relationship of the electromechanical coupling

constant K^2 and the normalized thickness of thin film.

Figs.41 and 42 are examples of the conventional acoustic wave devices of this type as disclosed in the Japanese unexamined patent publication "hei2-189011" (hereinafter document 3).

A description of the numbered components indicated in the figures follows: the electrode fingers 5; and a piezoelectric substrate 7.

An operation of the conventional film acoustic wave device is described using Figs.34 to 42.

In Figs.34 and 35, the electrode fingers 5 are placed on top of the glass substrate 1, and then the piezoelectric thin film 2 made of ZnO is placed on top of the two. An electric field is formed on an intersecting part of the electrode fingers 5 from electric signals applied to the interdigital transducer of input side 3. Due to the electric field, the piezoelectric thin film 2 is stretched to excite the acoustic waves. The acoustic waves that have been excited at the interdigital transducers of input side 3 propagates in a direction parallel to a surface, and reaches the interdigital transducers of output side 4 accompanied by the electric field and the acoustic vibrations. At the interdigital

transducers of output side 4, the electrode fingers 5 again receive the electric field which is formed by the acoustic waves, and change the electric field back to the electric signal. Since a reverse conversion of electric signals and acoustic waves is possible, the process of reverse conversion of the electric field made by the acoustic waves back to the electric signals is considered same as the case of the interdigital transducers of input side 3.

There are a number of modes for the propagation of acoustic waves through the piezoelectric thin film 2 as shown in Fig.35. Example of the modes are: surface acoustic waves which propagate in the direction parallel to the surface due to a concentration of energy at the surface; bulk waves which propagate in the direction parallel to the surface; and the bulk waves which propagates in a direction of thickness. For any of these modes, intensities of acoustic wave excitations are determined by materials being used, combination of the materials, the physical dimensions such as thickness of each material, as well as the configuration of electrodes that excites the acoustic waves. The film acoustic wave device of Fig.35 uses the surface acoustic waves. The configuration of electrode fingers 5 as shown in Figs.34 and 35 are commonly being used to excite the surface acoustic waves.

An efficiency of conversion from the electric signals which are applied to the interdigital transducers of input side 3 to the surface acoustic waves relates largely on a performance of the film acoustic wave device, and as one of a figure of merit that indicates the conversion efficiency, there is electromechanical coupling constant K^2. The larger the electromechanical coupling constant K^2, for example, the filters that are less damaging and having wide-ranging properties become possible. The electromechanical coupling constant K^2 is determined by the materials being used, the combination of the materials, the physical dimensions such as the thickness of each material, and the configuration of electrode that excites the acoustic waves.

The conventional film acoustic wave device of this type in the document 1 uses PbO-B_2O_3 glass with density ρ=5.7$\pm$0.3, Lamé's constant μ=(0.48$\pm$0.02)X10^{11}N/m^2, Poisson's ratio σ =0.25 as the glass substrate 1, as the electrode fingers 5 made of aluminum, and the piezoelectric thin film 2 made of ZnO. Thickness are: 0.1 μ m for the electrode fingers 5; 0.3 ~25.5 μ m for the piezoelectric thin film 2; and 0.1 μ m for the opposing electrodes 6. Fig.36 and 37 illustrate the properties of the film acoustic wave devices with this

configuration, as described in the document 1.

Fig.36 is a graph that shows a relationship between the acoustic velocity Vs and the normalized thickness of thin film kh. Fig.37 is a graph that shows a relationship between the electromechanical coupling constant K^2 and the normalized thickness of thin film kh.

In this content, h refers to a thickness of piezoelectric thin film 2, and k refers to a wave number of the surface acoustic waves that propagate in the direction parallel to the surface. The normalized thickness of thin film kh is a multiple of the wave number k and the thickness h. Given that a wavelength of the acoustic wave is λ, and a frequency is f, the wave number k is $(2\pi/\lambda)$ or $(2\pi f/Vs)$, so under a fixed frequency f the wave number k is also a fixed number that the normalized thickness kh on a horizontal axis is possible to be substituted with the thickness h. That is, under a fixed frequency f, Fig.36 is indicating a relationship of the acoustic velocity Vs and the thickness h of piezoelectric thin film 2, and even when the thickness h changes, the acoustic velocity Vs is fixed. Likewise, for a fixed frequency f, Fig.37 is showing the relationship of the thickness h of piezoelectric thin film 2 and the electromechanical coupling constant K^2, and in a range of

kh from 3 to 4, the electromechanical coupling constant K^2 is close to a maximum, indicating that it is also fixed.

Accordingly, by selecting materials of glass substrate 1, etc. as described previously, even if the thickness of piezoelectric thin film 2 varied, the acoustic velocity Vs and the electromechanical coupling constant K^2 for the film acoustic wave devices are almost fixed. The acoustic velocity Vs relates to a center frequency of the film acoustic wave device, and the electromechanical coupling constant K^2 largely relates to an insertion loss of the film acoustic wave device. Thus, within a range of the frequency f and the thickness h of piezoelectric thin film 2, the range of normalized thickness of the thin films kh is from 3 to 4 as in Figs.36 and 37, and the center frequency and the insertion loss of film acoustic wave device is approximately a fixed number.

Fig.38 is showing the conventional film acoustic wave device of this type as in the document 2, and is a cross-sectional view similar to Fig.35.

A description of the numbered components indicated in the figure follows: the glass substrate 1, the piezoelectric thin film 2 made of ZnO or aluminum nitride (AlN), and the

electrode fingers 5 that make up the interdigital transducers.

Similar to Figs.34 and 35, the conventional film acoustic wave device of this type shown in Fig.38 is using the surface acoustic waves. The configuration resembles the configuration shown in Fig.35 where the electrode fingers 5 are placed on top of the glass substrate 1, and then place the piezoelectric thin film 2 on top of the two. However, in the example of Fig.38, the opposing electrodes 6 are not placed on top of the piezoelectric thin film 2. The fact that the surface acoustic waves are excited by the electric field formed at the intersecting electrode fingers 5 is same as in Figs.34 and 35, but because the surface of piezoelectric thin film 2 has no metal on its surface, the film acoustic wave device of Fig.38 has different properties from the example illustrated in Figs.34 and 35.

Fig.39 shows a relationship of the normalized thickness of thin film kh and the acoustic velocity Vs. Fig.40 shows a relationship of the normalized thickness of thin film kh and the electromechanical coupling constant K^2.

Although the materials being used and the configuration are similar to those of Figs.34 and 35, a reason for the film

acoustic wave device illustrated in Fig.38 being so different in properties from Figs.36 and 37 is the non-metallic surface of the piezoelectric thin film 2. A case illustrated in Fig.39 is different from the case illustrated in Fig.36, where the acoustic velocity Vs changes when the normalized thickness of thin film kh changed. On the other hand, at a region of the normalized thickness of thin film kh greater than 2, the electromechanical coupling constant K^2 becomes greater than 2. Therefore, when change the thickness h of piezoelectric thin film 2 at the region of normalized thickness of thin film kh greater than 2, the acoustic velocity Vs changes but the electromechanical coupling constant K^2 does not change in great deal. This means, the center frequency of film acoustic wave device is adjusted by directly changing the thickness h of piezoelectric thin film 2. In the document 2, as methods of adjusting the thickness h of piezoelectric thin film 2, for example, illustrates the use of a sputter to make a thicker film and a use of etching method to make a thinner film. As long as the configuration is like those illustrated in Fig.38, there will be no effect on the electrode fingers 5 by changing the thickness of piezoelectric thin film 2 using the etching or sputtering methods.

Figs.41 and 42 illustrate the conventional acoustic wave

devices of this type as disclosed in document 3.

For those cases, the piezoelectric substrate 7 is used instead of the piezoelectric thin film 2. A numeral 5 is indicating the electrode fingers 5.

The conventional acoustic wave device of the type shown in Fig.41 is the surface acoustic wave device used by exciting the surface acoustic waves by the electrode fingers 5. The velocity of surface acoustic waves that propagate through the electrode fingers 5 is known to have a different acoustic velocity from the acoustic velocity at a region where there is no electrode fingers 5, and this is due to effects of a mass load and an electrical boundary condition of the electrode fingers 5. For the surface acoustic wave device of Fig.41, by changing the thickness of electrode fingers 5 by etching the electrode material, the acoustic velocity is changed by the mass load effect, and then the center frequency of the surface acoustic wave device is adjusted. For a detailed description on the effects of change in frequency from the mass load effect, refer to "Journal of Electronics, Information and Communication Engineers of Japan A, Vol.J74-A, No.9, pp.1359～1365, Sept. 1991" (hereinafter document 4).

For the conventional acoustic wave device of this type shown in Fig.42, parts of the piezoelectric substrate 7 are scraped off where there is no electrode fingers 5 using the etching method, to adjust the center frequency. With such structure where the surface of piezoelectric substrate 7 has been scraped off as in Fig.42, in areas of different surface levels of the piezoelectric substrate 7, a delay is known to arise from an influence of stored energy on the surface acoustic waves that propagate through the different surfaces of piezoelectric substrate 7. The varied surface levels allows for an equivalent adjustment of the center frequency of the surface acoustic wave device. For a detailed description of the adjustment of center frequency from the etching method the surface of piezoelectric substrate 7, refer to "IEEE Transactions on Sonics and Ultrasonics, Vol.SU-29, No.6, pp.299~310, November 1982" (hereinafter document 5).

Case of forming the piezoelectric thin film 2 and a metal electrode is described using Figs.43 and 44.

Standard processes of forming the piezoelectric thin film 2 and the metal electrode are the sputtering and a vacuum evaporation. In these methods of forming the films, looking from a target 8 of the sputter and vacuum evaporation, at a central portion of wafer the resulting film becomes

relatively thick, and at periphery of the wafer the resulting film becomes relatively thin. For example, as in Fig.43 when the target 8 and the wafer 9 where the film components land are arranged one-to-one inside a vacuum container 10, then the formation of film in the central portion of wafer 9 is thick of h_C and in the periphery of wafer 9 is thin of h_e, as shown in Fig.44. Therefore, in this type of film acoustic wave device, the adjustment of frequency was needed to overcome the variation in the thickness of piezoelectric thin film and film formed on the metal electrode.

Disclosure of the Invention

As explained previously, for the conventional film acoustic wave device of this type, types and combinations of materials for the glass substrate 1, the piezoelectric thin film 2 and the electrode fingers 5 were defined within the appropriate limit. By limiting the types, combinations and thickness within the allowed thickness change for the piezoelectric thin film 2, variations in the thickness of piezoelectric thin film 2 caused during manufacturing are dealt with by planning the film acoustic wave device in such a way that there will be no huge variations in its properties. However, in such a case there is a problem of not being able to use it for other types of film acoustic wave device other than the one geared to the defined limit of combinations and types

of the materials for the glass substrate 1, the piezoelectric thin film 2 and the electrode 5, therefore, it could not have been adopted in a wide-ranging types of film acoustic wave devices.

Also, for the conventional acoustic wave devices, center frequencies are adjusted by changing the thickness of piezoelectric substrate 7 partially, the thickness of piezoelectric thin film 2 and the electrode fingers 5. Normally, for this type of the acoustic wave devices, a plurality of these devices are arranged on top of the wafer made of a single plate of glass substrate or the piezoelectric substrate 7, and the plurality of these devices are manufactured at once. From this, when need to partially change the thickness of piezoelectric thin film 2, the thickness of electrode fingers 5, and the thickness of piezoelectric conductor 7, the thickness are adjusted in a wafer unit or adjusted after separating the individual devices from each other for adjustment of every one of the devices. To carry out the adjustment for every devices, an additional adjustment expense is incurred directly on top of a cost of the device, therefore, it is not practical for the price of this type of the acoustic wave devices. If the thickness were adjusted in the wafer unit, it cannot be adopted in a case when the variation of thickness arose inside

the wafer.

That is, when forming the metal electrode and the piezoelectric thin film using the sputtering and vacuum evaporation, as previously mentioned in Fig.44, the films formed on top of the wafer 9 is thick at central portion and thin in its periphery. Such that in this type of film acoustic wave device, it is important to adjust frequency against the variation in thickness of films of metal electrode and piezoelectric thin film within the wafer, however, a problem in the conventional film acoustic wave device was that the adjustment was not possible.

The invention, in attempt to solve the problem, aims to provide a film acoustic wave device and a manufacturing method of film acoustic wave device that can adjust a variation of thickness inside the wafer, without increasing the manufacturing cost.

According to one aspect of the present invention, a film acoustic wave device comprises a wafer made of a semiconductor substrate, a ground electrode formed on top of the semiconductor substrate, a piezoelectric thin film formed on top of the ground electrode, and an upper electrode formed on top of the piezoelectric thin film. A pattern

shape for the film acoustic wave device is changed by a position at the wafer.

According to another aspect of the present invention, a length of the upper electrode of the film acoustic wave device is changed by the position at the wafer.

According to another aspect of the present invention, a width of the upper electrode of the film acoustic wave device is changed by the position at the wafer.

According to another aspect of the present invention, the upper electrode of the film acoustic wave device includes a plurality of upper electrodes, and distances between the upper electrodes are changed by the position at the wafer.

According to another aspect of the present invention, the film acoustic wave device further comprises a bonding pad for connecting with the upper electrode. A shape of the bonding pad is changed by the position at the wafer.

According to another aspect of the present invention, the film acoustic wave device according to claim 5 further comprises a connecting pattern for connecting the upper electrode with the bonding pad. A shape of the connecting

pattern is changed by the position at the wafer.

According to another aspect of the present invention, the connecting pattern of the film acoustic wave device forms an air bridge.

According to another aspect of the present invention, the film acoustic wave device further comprises a capacitor provided on the same semiconductor substrate as the film acoustic wave device. A capacity of the condenser is changed by the position of the wafer.

According to another aspect of the present invention, the film acoustic wave device includes the followings: semiconductor substrate made of gallium arsenide (GaAs); the piezoelectric thin film made of lead titanate ($PbTiO_3$); and at least one of the upper electrodes and ground electrode which is a conductor substantially made of platinum (Pt).

According to another aspect of the present invention, the film acoustic wave device includes the followings: a semiconductor substrate made of silicon (Si); the piezoelectric thin film made of lead titanate ($PbTiO_3$); and at least one of the upper electrode and ground electrode which is a conductor substantially made of platinum (Pt).

According to another aspect of the present invention, the film acoustic wave device includes the followings: the piezoelectric thin film made of PZT($PbTiO_3$-$PbZrO_3$); and at least one of the upper electrode and the ground electrode which is a conductor substantially made of platinum (Pt).

According to another aspect of the present invention, the piezoelectric thin film of the film acoustic wave device is made of zinc oxide (ZnO).

According to another aspect of the present invention, the piezoelectric thin film of the film acoustic wave device is made of aluminum nitride (AlN).

According to another aspect of the present invention, the film acoustic wave device further comprises an inductor between the semiconductor substrate and the ground electrode.

According to another aspect of the present invention, a circuit device comprises a substrate, and a plurality of elements formed on the substrate. The pattern shape of the elements formed on the substrate is changed by a position at the substrate.

According to another aspect of the present invention, a manufacturing method of the film acoustic wave device comprises of the following steps:

(a) forming a ground electrode on top of a wafer made of a semiconductor substrate;

(b) forming a piezoelectric thin film on top of the ground electrode;

(c) forming an upper electrode on top of the piezoelectric thin film; and

(d) changing a pattern shape of the upper electrode formed on top of the piezoelectric thin film by the position at the wafer.

According to another aspect of the present invention, the manufacturing method of the film acoustic wave device includes the step of changing the pattern shape. The step includes a step of changing the length of the upper electrode by the position at the wafer.

According to another aspect of the present invention, the manufacturing method of the film acoustic wave device includes the step of changing the pattern shape. The step includes a step of changing the width of the upper electrode by the position at the wafer.

According to another aspect of the present invention, the manufacturing method of the film acoustic wave device includes the step of forming the upper electrode which forms a plurality of upper electrodes. The step of changing the pattern shape includes a step of changing the distance between the upper electrodes by the position at the wafer.

According to another aspect of the present invention, the manufacturing method of the film acoustic wave device includes the step of forming the upper electrode. This step further includes a step of connecting of the upper electrode to a bonding pad. As well, the manufacturing method of the film acoustic wave device includes step of changing the pattern shape. This step further includes a step of changing a shape of the bonding pad by the position at the wafer.

According to another aspect of the present invention, the manufacturing method of the film acoustic wave device includes the step of forming the upper electrode. This step further includes the connecting the upper electrode and the bonding pad to a connecting pattern. As well, the manufacturing method of the film acoustic wave device includes the step of changing the pattern shape. This step further includes a step of changing a shape of the connecting

pattern by the position at the wafer.

According to another aspect of the present invention, the manufacturing method of the film acoustic wave device includes the step of changing the pattern shape which further includes a step of forming the connecting pattern with the air bridge.

According to another aspect of the present invention, the manufacturing method of the film acoustic wave device further comprises a step for setting a capacitor on the same semiconductor substrate as the film acoustic wave device. The step of changing the pattern shape further includes a step of changing a capacity of the condenser by the position at the wafer.

Brief description of the drawings

Fig.1 illustrates the film acoustic wave devices for embodiment 1 of the invention;

Fig.2 is an enlarged diagram of the film acoustic wave device of Fig.1;

Fig.3 is a cross-section of the film acoustic wave device of Fig.2;

Fig.4 illustrates an equivalent circuit of the film acoustic wave device of Fig.2;

Fig.5 is the cross-section of upper electrode area for the film acoustic wave device of Fig.2;

Fig.6 is a graph showing calculated results of frequency response upon changing the resonating frequency of film acoustic wave device;

Fig.7 illustrates the film acoustic wave devices for embodiment 2;

Fig.8 is the graph showing the calculated results of frequency response of the film acoustic wave device for embodiment 2;

Fig.9 illustrates the film acoustic wave devices for embodiment 3;

Fig.10 is the graph showing the calculated results of frequency response of the film acoustic wave device for embodiment 3;

Fig.11 illustrates the film acoustic wave devices for embodiment 4;

Fig.12 is the graph showing the calculated results of frequency response of the film acoustic wave device for embodiment 4;

Fig.13 illustrates the film acoustic wave devices for embodiment 5;

Fig.14 is the graph showing the calculated results of frequency response of the film acoustic wave device for embodiment 5;

Fig.15 illustrates the film acoustic wave devices for embodiment 6;

Fig.16 is the graph showing the calculated results of frequency response of the film acoustic wave device for embodiment 6;

Fig.17 illustrates the film acoustic wave devices for embodiment 7;

Fig.18 is the graph showing the calculated results of frequency response of the film acoustic wave device for embodiment 7;

Fig.19 illustrates the film acoustic wave devices for embodiment 8;

Fig.20 is the enlarged diagram of the film acoustic wave device of Fig.19;

Fig.21 is the cross-section of the film acoustic wave device of Fig.20;

Fig.22 illustrates the film acoustic wave device for embodiment 9;

Fig.23 is the enlarged diagram of the film acoustic wave device of Fig.22;

Fig.24 is the cross-section of the film acoustic wave device of Fig.23;

Fig.25 illustrates the film acoustic wave device for embodiment 10;

Fig.26 is the enlarged diagram of the film acoustic wave

device of Fig.25;

Fig.27 is the cross-section of the film acoustic wave device of Fig.26;

Fig.28 illustrates the film acoustic wave devices for embodiment 11;

Fig.29 is the enlarged diagram of the film acoustic wave device of Fig.28;

Fig.30 is the cross-section of the film acoustic wave device of Fig.29;

Fig.31 illustrates the film acoustic wave devices for embodiment 12;

Fig.32 is the enlarged diagram of the film acoustic wave device of Fig.31;

Fig.33 is the cross-section of the film acoustic wave device of Fig.32;

Fig.34 illustrates a conventicnal type of the film acoustic wave device;

Fig.35 is the cross-section of the conventional type of film acoustic wave device of Fig.34;

Fig.36 is the graph showing a relationship of the acoustic velocity and the normalized thickness of thin film for the conventional type of film acoustic wave device as in Figs.34 and 35;

Figs.37 is the graph showing the relationship between the normalized thickness and the electromechanical coupling

constant for the conventional type of film acoustic wave device as in Figs.34 and 35;

Fig.38 illustrates the conventional type of film acoustic wave device;

Fig.39 is the graph showing the relationship between the normalized thickness of thin film and the acoustic velocity for the conventional type of film acoustic wave device of Fig.38;

Fig.40 is the graph showing the relationship between the electromechanical coupling constant and the normalized thickness of thin film for the conventional type of film acoustic wave device of Fig.38;

Fig.41 illustrates a frequency adjustment method for the conventional type of film acoustic wave device;

Fig.42 illustrates a frequency adjustment method for the conventional type of film acoustic wave device;

Fig.43 is an apparatus for forming the piezoelectric thin film showing an example of wafer and target arrangement; and

Fig.44 illustrates an example of thickness distribution of the piezoelectric thin film on top of the wafer.

Best mode for carrying out the invention

Embodiment 1.

Fig.1 illustrates the film acoustic wave devices for embodiment 1.

Fig.2 is an enlarged diagram of the film acoustic wave device shown in Fig.1. Fig.3 is a cross-section B-B of Fig.2.

A description of the numbered components indicated in the figure follows: a wafer 11 is a semiconductor made of gallium arsenide (GaAs); film acoustic wave devices 12a~12c formed on top of the wafer 11; an orientation flat 13 showing the standard surface of the wafer 11; a semiconductor substrate 14 made of gallium arsenide (GaAs); a ground electrode 15; bonding pads 16 at same electric potential as the ground electrode 15; a piezoelectric thin film 17 made of lead titanate ($PbTiO_3$); upper electrodes 18a and 18b; connecting patterns 19a and 19b; bonding pads 20a and 20b respectively connected to the upper electrodes 18a and 18b; and a via hole 21.

A film acoustic wave device 12 shown in Fig.2 is a filter made of a single upper electrode of input side 18a and a single upper electrode of output side 18b. This filter uses bulk waves, unlike the surface acoustic wave filter. That is, the filter uses the resonance of thickness direction and resonance between the upper electrode of input side 18a and upper electrode of output side 18b, using a fewer number of electrodes than the surface acoustic wave filters. The

filter has the following pattern dimensions: length of upper electrodes 18a and 18b is Le; width is We; and distance between the upper electrode of input side 18a and upper electrode of output side 18b is La. Length of connecting patterns 19a and 19b is Lg and width is Wa. The Fig.3 shows a use of air bridge to the connecting patterns 19a and 19b. The measurements of each pattern Le, We, Lg, La and Wa determines the frequency response of the film acoustic wave device 12 as well as the thickness h of piezoelectric thin film 17.

Normally, when manufacturing this type of film acoustic wave device 12, as Fig.1 is showing, a plurality of film acoustic wave devices 12a~12c are arranged on top of a single wafer 11. In reality, 100 or more of film acoustic wave devices are arranged, however, for the purpose of simplicity, Fig.1 has been simplified. Since a several number of the film acoustic wave devices 12a~12c are arranged on top of the single wafer 11, much number of the film acoustic wave devices 12 can be manufactured at once from a processing of the single wafer 11. A cost of the processing of single wafer 11 does not question a number of film acoustic wave devices 12, but the cost is determined by the number of wafer processing. The greater the number of film acoustic wave devices 12 obtained from the single wafer, the cost of manufacturing

per film acoustic wave device 12 becomes low. In addition, more than one wafer can be processed at one wafer processing which will further reduce the manufacturing cost.

In this type of film acoustic wave device, the vacuum evaporation or the sputtering are commonly used in forming the films on ground electrode 15, the piezoelectric thin film and upper electrodes 18a and 18b. The lower electrode 15, the piezoelectric thin film 17 and the upper electrodes 18a and 18b are formed inside a surface of the wafer 11, and all tend to have a slight variation in thickness distribution. What is meant by the thickness distribution here is a structural change in film component. For example, when sputtering the piezoelectric thin film 17 onto a single wafer, as Fig.44 shows, a central portion of the wafer becomes thick and a periphery of the wafer becomes thin. The thickness distribution is also affected by a condition of the wafer at the sputtering. For instance, when rotating the wafer inside a sputtering apparatus, this may result in the thickness distribution in a form of band at a central portion of the wafer. A variation in the thickness of piezoelectric thin film 17 is a change in frequency upon manufacturing the film acoustic wave device 12.

Due to this, when arrange a plurality of the film acoustic

wave devices with the same pattern measurements Le, We, Lg, La and Wa on a single wafer 11, for example, at a central part of the wafer 11 where the piezoelectric thin film 17 is thick, a frequency of the film acoustic wave device 12a decreases at the central part of wafer 11, and at a periphery of the wafer 11 where the piezoelectric thin film 19 becomes thinner compared to the central part of the wafer, the frequency of film acoustic wave device 12b is increases. In the film acoustic wave devices of this invention, by changing at least more than one of the pattern measurements Le, We, Lg, La and Wa, the frequency at the central part and the periphery of the wafer for the film acoustic wave devices are adjusted. In Fig.1, at least more than one of the pattern measurements Le, We, Lg, La and Wa are changed for the film acoustic wave device 12c in a direction perpendicular to the orientation flat 13, the film acoustic wave device 12b in a direction parallel to the orientation flat 13. A concrete description on the methods of changing the pattern measurements will follow in the embodiments.

A description on the equivalent circuit used in the following embodiments are given below.

Figs.4 to 6 are diagrams describing calculations of the frequency responses.

Fig.4 shows the equivalent circuit of the film acoustic wave device 12 of Fig.2.

Fig.5 is a cross-section for regions of the upper electrode of input side 18a and the upper electrode of output side 18b for the film acoustic wave device 12.

In Fig.4, a part enclosed in square with dashed line is the equivalent circuit 24 for a bulk acoustic wave filter. The equivalent circuit 24 is connected to the part corresponding to the section from the upper electrode of input side 18a to the upper electrode of output side 18b. The equivalent circuit 24 of the bulk acoustic wave filter is corresponding to a path of signal from the upper electrode of input side 18a to the upper electrode of output side 18b, as shown in Fig.5. When all of the pattern measurements Le, We, Lg, La and Wa are changed, element values of the equivalent circuit 24 for the bulk acoustic wave filter are changed. Upper capacitors C_{S1}, C_{S2}, and C_{i0}, an inductor L_{S1}, and a resistor R_{S1} for the equivalent circuit 24 of bulk acoustic wave filter are stray components of the connecting patterns 19a and 19b and the bonding pads 20a and 20b for the film acoustic wave device 12. The capacitor C_{S1} represents a capacitance of the bonding pads 20a and 20b and a capacitive reactance of

the connecting patterns 19a and 19b. The capacitor C_{s2} represents a capacitance of upper electrodes 18a and 18b (except for the piezoelectric thin film 17) and the capacitive reactance of the connecting patterns 19a and 19b. The capacitor C_{i0} represents a capacitance between the upper electrode of input side 18a and the upper electrode of output side 18b. The inductor L_{s1} represents an inductive reactance of the connecting patterns 19a and 19b. The resistor R_{s1} represents a resistance such as a conductor resistance of the electrodes 18a and 18b, the connecting patterns 19a and 19b, and the bonding pads 20a and 20b. For a detailed description of the equivalent circuit 24 of bulk acoustic wave filter, refer to the following journals: "Journal of Electronics, Information and Communication Engineers of Japan, '76/11, Vol.J59-A, No.11, pp.985-992, 1976" (hereinafter document 6), "Journal of Electronics, Information and Communication Engineers of Japan, '79/1, Vol.J62-A, No.1, pp.8-15. 1979" (hereinafter document 7), and "Journal of Electronics, Information and Communication Engineers of Japan, '80/6, Vol.J63-A, No.6, pp.327-334, 1980" (hereinafter document 8).

Fig.6 is a graph showing the frequency response of the film acoustic wave device 12 calculated using the equivalent circuit of Fig.4.

The graph shows the following frequency response: a dashed line represents a resonant frequency f_o of 2.5GHz; a double dotted line represents the resonant frequency f_o of 2.52GHz; a single dotted line represents the resonant frequency f_o of 2.54GHz; a dotted chained line represents the resonant frequency f_o of 2.56GHz; and a plain line represents the resonant frequency f_o of 2.58GHz. A density of the piezoelectric thin film is 7700kg/m^3, a relative dielectric constant is 200, a parallel resonance of Q which determines a resistor r_s is 500, a series resonance of Q which determines a conductance g_s is 500, a normalized length of electrode (Le/h) is 10, a normalized distance between electrodes (Lg/h) is 0.6, a normalized width of electrode (We/h) is 111, the thickness is approximately 0.9μm, C_{s1} is 0.8pF, C_{s2} is 0.2pF, C_{io} is 0.02pF, L_{s1} is 8nH, and R_{s1} is 6 Ω. An effective piezoelectric constant of electrode is 4.0C/m, a propagation loss of acoustic wave along to a surface of the electrode is 3dB/100μm, a normalized cutoff frequency (f_m/f_o) is 0.734, a constant which determines a gradient of dispersion property is -14.9754, an effective piezoelectric constant of the electrode part is 0.2C/m, a propagation loss of acoustic wave along to a surface of the electrode is 3dB/100 μ m, the

normalized cutoff frequency (f_n/f_o) is 0.802, the constant which determines gradient of dispersion property is -17.5854. The values are obtained from the piezoelectric thin film 17 made of lead titanate ($PbTiO_3$) and the ground electrode 15 and the upper electrodes 18a and 18b made of platinum (Pt). The resonant frequency f_o represents a thickness-extensional wave provided that both sides of the piezoelectric thin film 17 are free surfaces, and provided that the acoustic velocity of the thickness-extensional wave is Vs, the following expression is established for the resonant frequency f_o:

$$f_o = Vs/(2h)$$

That is, if the piezoelectric thin film 17 on top of the wafer 11 is uniform in material quality, and if the acoustic velocity Vs for the thickness-extensional wave is fixed, the resonant frequency f_o of the thickness-extensional wave is inversely proportional to the thickness h of the piezoelectric thin film 17. Therefore, as in Fig.6, when the resonant frequency f_o changes from 2.5GHz to 2.58GHz, the thickness h of the piezoelectric thin film 17, as opposed to the thicker type of thickness h_c corresponding to resonant frequency f_o = 2.5GHz, the thinner type of thickness h_e

corresponding to resonant frequency f_O = 2.58GHz is 2.5/2.58 = 0.969 times the thicker type.

From the example in Fig.6, responding to the change in the resonant frequency f_O, a change in the frequency response for the film acoustic wave device 12 is observed at a frequency axis. That is, the change in the thickness h of piezoelectric thin film 17 itself becomes a lag in frequency of a passband for the film acoustic wave device 12.

The following embodiments take this presumption and are using the equivalent circuit of Fig.4.

Embodiment 2.

Fig.7 illustrates the film acoustic wave device for embodiment 2.

A description of the numbered components indicated in Fig.7 follows: the wafer 11, the film acoustic wave device 12a in a central part of the wafer; the film acoustic wave device 12b in a peripheral part of the wafer that parallels in the direction of orientation flat 13; the film acoustic wave device 12c in the peripheral part of the wafer that is perpendicular to the direction of orientation flat 13; and the upper electrode of input side 18a and the upper electrode

of output side 18b.

In Fig.7 of the present embodiment, the distances Lg between the upper electrodes of input side 18a and output side 18b are changed for the film acoustic wave device 12a at the central wafer and the film acoustic wave devices 12b and 12c at the peripheral wafer.

Fig.8 shows the calculated results of frequency response when the distances Lg between the electrodes are changed.

As described previously in Fig.6, the frequency response are calculated using the equivalent circuit of Fig.4. In Fig.8, the frequency response are calculated by changing the normalized distance between the electrodes (Lg/h) from 0.4 to 0.7. The normalized length of electrode (Le/h) is 10, and the normalized width of electrode (We/h) is 111, and all other calculation parameters are same as in Fig.6.

As apparent from Fig.8, when increase the normalized distance between the electrodes (Lg/h) the passband shifts to a higher region of frequency. When the normalized distance between the electrodes (Lg/h) is increased by 0.05, the passband shifts to the high frequency side by 2MHz. But, when the normalized distance between the electrodes (Lg/h) declines,

a loss fluctuation inside a band is large, meaning there is in fact a limit to the normalized distance between electrodes that can be applied for an adjustment of the passband. Such limitation depends on a type of piezoelectric thin film 17 being used, thickness h of the piezoelectric thin film, a type, thickness, and measurements of electrodes and stray components such as the element value of the circuit shown in Fig.4. That is, in the calculation example of Fig.8 shows the normalized distances between the electrodes (Lg/h) are from 0.4 to 0.7, however, if the type of piezoelectric thin film 17, the thickness of piezoelectric thin film 17, the type of electrode, the thickness, the measurements and the stray components such as the element value of equivalent circuit are different from Fig.8, then an appropriate range for the normalized distance between the electrodes (Lg/h) will be different from the case shown in Fig.8.

Embodiment 3.

Fig.9 illustrates the film acoustic wave device for embodiment 3.

A description of the numbered components indicated in Fig.9 follows: the wafer 11, the film acoustic wave device 12a in a central part of the wafer; the film acoustic wave device 12b in the peripheral part of the wafer that parallels in

the direction of orientation flat 13; the film acoustic wave device 12c in the peripheral part of the wafer that is perpendicular to the direction of orientation flat 13; and the upper electrode of input side 18a and the upper electrode of output side 18b.

In Fig.9 of the present embodiment, width We of the upper electrodes 18a and 18b are changed for the film acoustic wave device 12a of the central wafer 11 and the film acoustic wave devices 12b and 12c of the peripheral wafer 11.

Fig.10 shows the calculated results of the frequency response when the normalized width of electrodes (We/h) are changed.

The frequency response are calculated by changing the normalized width of electrodes (We/h) from 111 to 66.7. The normalized length of electrode (Le/h) is 10, the distance between the normalized electrodes (Lg/h) is 0.6, and all other calculation parameters are same as in Fig.6.

In the calculation example shown in Fig.10, when the normalized width (We/h) are changed, and a change at a low frequency side of the passband (X1 in the diagram) is slight whereas in a high frequency side of the passband (Y1 in the diagram) the change is large. The passband is shifting to

the higher frequency region when the width of normalized electrode (We/h) are increased. When compare the calculation example of the change in normalized distances between the electrodes (Lg/h) in Fig.8, with the change in the width of normalized electrodes (We/h) of Fig.10, within the realms of calculation shown in Figs.8 and 10, an amount of change for the passband is larger for the change made in the normalized electrode distance (Lg/h). However, if the calculation example of the normalized electrode distance (Lg/h) in Fig.8 is changed very slightly by 0.05, the passband shifts approximately by 2MHz that it opens a possibility of manufacturing error of the normalized distance between electrodes (Lg/h) to cause variation in the passband. Therefore, as a precise adjustment of the passband, a method to change the passband slightly is suitable, similar to the case of changing the width of normalized electrode (We/h) of Fig.10. When changed the normalized width of electrode (We/h) approximately by 10, an amount of the passband shifting is maximum of approximately 2MHz. The amount of shifting, compared to the manufacturing error, is sufficiently large that there is no need to concern about the variation of passband caused by the manufacturing error of normalized width electrode (We/h).

Here, what is meant by the low frequency side of the passband

is, it is an edge of the passband on a low frequency side that are increased by a required amount from a minimum loss value of the passband. The high frequency side of the passband is another edge of the passband on a high frequency side that are increased by the required amount from the minimum loss value of the passband. The required amount for increase from the minimum loss value is normally 3dB. In this case, a difference in frequency of the passband on the high frequency side from the low frequency side is called bandwidth 3dB.

Embodiment 4.

Fig.11 illustrates the film acoustic wave device for embodiment 4.

A description of the numbered components indicated in Fig.11 follows: the wafer 11, the film acoustic wave device 12a in a central part of the wafer; the film acoustic wave device 12b in a peripheral part of the wafer that parallels in the direction of orientation flat 13; the film acoustic wave device 12c in the peripheral part of the wafer that is perpendicular to the direction of orientation flat 13; and the upper electrode of input side 18a and the upper electrode of output side 18b.

In Fig.11 of the present embodiment, the length Le for the upper electrodes 18a and 18b are changed for the film acoustic wave device 12a at the central wafer and the film acoustic wave devices 12b and 12c at the peripheral wafer.

Fig.12 shows the calculated results of the frequency response when the normalized length of electrodes (Le/h) are changed.

The frequency response are calculated by changing the normalized length of electrodes (Le/h) from 8 to 12. The normalized width of electrodes (We/h) are 111, and the normalized distance between the electrodes (Lg/h) is 0.6, and all other calculation parameters are same as in Fig.6.

In the calculation example shown in Fig.12, when increase the normalized length of electrodes (Le/h) the passband tends to narrow down. In the regions of passbands, a change taking place in the passband of low frequency side (X2) is larger than the change taking place in the passband of high frequency side (Y2), and as a result, when increase the normalized length of electrodes (Le/h) the passband will shift to the high frequency side.

Embodiment 5.

Fig.13 illustrates the film acoustic wave device for

embodiment 5.

A description of the numbered components indicated in Fig.13 follows: the wafer 11, the film acoustic wave device 12a in a central part of the wafer; the film acoustic wave device 12b in a peripheral part of the wafer that parallels in the direction of orientation flat 13; the film acoustic wave device 12c in the peripheral part of the wafer that is perpendicular to the direction of orientation flat 13; and the connecting patterns 19a and 19b.

In Fig.13 of the present embodiment, length La of the connecting patterns 19a and 19b are changed for the film acoustic wave device 12a at the central wafer and for the film acoustic wave device 12b at the peripheral wafer. Width Wa of the connecting patterns 19a and 19b are also changed for the film acoustic wave device 12a at the central wafer and the film acoustic wave device 12c at the peripheral wafer.

In Fig.14 shows a result of the frequency response upon changing the inductor L_{S1} shown in Fig.4.

The inductor L_{S1} is calculated by changing its inductance from 4nH to 12nH. The inductance of inductor L_{S1} mainly changes by changing at least one of a length La or a width

Wa of connecting patterns 19a and 19b. The normalized width of electrode (We/h) is 77.8, and the normalized length of electrode (Le/h) is 10, and the normalized distance between the electrodes (Lg/h) is 0.6, and all other calculation parameters are same as in Fig.6.

In the calculation example shown in Fig.14, when inductance of the inductor L_{S1} increases from 4nH to 10nH, the passband of low frequency side (X3) does not almost at all change, and passband of high frequency side (Y3) changes to the higher frequency. This is indicating that when the inductance of inductor L_{S1} gets large, a band width for the passband becomes larger, in addition, the passband changes to the higher frequency side. When the inductor L_{S1} is 12nH, the higher frequency side of passband is lower than inductor L_{S1} of 10nH. This is an indication of the appropriateness of the value of inductor L_{S1} below 10nH in the calculation example of Fig.14.

Fig.13 of the present embodiment is showing a case of changing both the length La and the width Wa of connecting patterns 19a and 19b, however, a case can be made to change the length La of connecting patterns 19a and 19b. Alternatively, a case to change only the width Wa of connecting patterns 19a and 19b is also possible. Furthermore, the length La and the

width Wa of connecting patterns 19a and 19b can both be changed at the same time.

Embodiment 6.

Fig.15 illustrates the film acoustic wave device for embodiment 6.

A description of the numbered components indicated in Fig.15 follows: the wafer 11, the film acoustic wave device 12a in a central part of the wafer; the film acoustic wave device 12b in a peripheral part of the wafer that parallels in the direction of orientation flat 13; the film acoustic wave device 12c in the peripheral part of the wafer that is perpendicular to the direction of orientation flat 13; the connecting patterns 19a and 19b; and the bonding pads 20a and 20b.

In Fig.15 of the present embodiment, for the film acoustic wave device 12a at the central wafer and the film acoustic wave devices 12b and 12c at the peripheral wafer, length La and width Wa for connecting patterns 19a and 19b and areas of bonding pads 20a and 20b are changed. This is equivalent to changing the capacitance of capacitor C_{S1} shown in Fig.4.

Fig.16 shows a calculated result of the frequency response

when the capacitor C_{S1} shown in Fig.4 is changed.

The capacitor C_{S1} is calculated by changing its capacitance from 0.4pF to 1.2pF. The capacitance of capacitor C_{S1} mainly change by changing the followings: area of bonding pads 20a and 20b; capacitance of the capacitor electrically connected to bonding pads 20a and 20b; and the length La and the width Wa of connecting patterns 19a and 19b. The normalized width of electrode (We/h) is 77.8, the normalized length of electrode (Le/h) is 10, and the normalized distance between the electrodes (Lg/h) is 0.6, and all other calculation parameters are same as in Fig.6.

In the calculation example of Fig.16, when the capacitance of capacitor C_{S1} becomes large, low frequency side of passband gradually shift to high frequency side, and the high frequency side of passband will shift to the low frequency side. When this happens, the amount of shifting to the high frequency side is greater than the amount of shifting to the low frequency side, as a result, when the capacitance of capacitor C_{S1} gets large, the band width of passband narrows, at the same time shifts to the low frequency side.

Embodiment 7.

The Fig.17 illustrates the film acoustic wave device for embodiment 7.

A description of the numbered components indicated in Fig.17 follows: the wafer 11, the film acoustic wave device 12a in a central part of the wafer; the film acoustic wave device 12b in a peripheral part of the wafer that parallels in the direction of orientation flat 13; the film acoustic wave device 12c in the peripheral part of the wafer that is perpendicular to the direction of orientation flat 13; and the connecting patterns 19a and 19b.

In Fig.17 of the present embodiment, length La and width Wa of the connecting patterns 19a and 19b are changed for the film acoustic wave device 12a at the central wafer, and the film acoustic wave devices 12b and 12c at the peripheral wafer. This is equivalent to changing the capacitor C_{S2} of Fig.4.

Fig.18 is a calculated result of the frequency response when the capacitor C_{S2} shown in Fig.4 is changed.

The capacitor C_{S2} is calculated by changing its capacitance from 0.1pF to 0.5pF. The capacitance of capacitor C_{S2} mainly changes by changing the length La or width Wa of connecting patterns 19a and 19b, and by changing the shape and area of

upper electrodes 18a and 18b. The normalized width of electrode (We/h) is 77.8, the normalized length of electrode (Le/h) is 10, the normalized distance between the electrodes (Lg/h) is 0.6, and all other calculation parameters are same as in Fig.6.

In the calculation example shown in Fig.18, when the capacitance of capacitor C_{S2} increases from 0.2pF to 0.5pF, the higher frequency side of passband does not almost at all change and the low frequency side of passband shifts to the low frequency side. When the capacitance of capacitor C_{S2} gets large from 0.2pF to 0.5pF, the band width of the passband gets large, as well the passband shifts to the low frequency side. When the capacitance of capacitor C_{S2} is 0.1pF, compared to the capacitance of capacitor C_{S2} of 0.2pF, the passband of high frequency side will shift further to the low frequency side. Therefore, in the calculation example of Fig.18, the capacitance of capacitor C_{S2} greater than 0.2pF is suitable for use.

As shown in the calculation examples from Figs.8 to 18, the passband of the film acoustic wave devices 12 can be controlled by changing the length Le and width We of the upper electrodes 18a and 18b, the distance Lg between the upper electrodes 18a and 18b, the length La and width Wa of the

connecting patterns 19a and 19b, the areas of the bonding pads 20a and 20b, and the capacitance of capacitor connected electrically to the bonding pads 20a and 20b. By utilizing these when compensating for the variation of passband for the film acoustic wave device 12 caused from the thickness distribution of the piezoelectric thin film 17 on top of the wafer, able to obtain the film acoustic wave device with constant passband without it being dependent on a wafer positioning. The compensation of variation of passband for the film acoustic wave device 12 due to the thickness distribution of piezoelectric thin film 17 on top of the wafer, for instance, as Fig.1 shows, is carried out by changing the length Le and width We of the upper electrodes 18a and 18b, the distance Lg between the upper electrodes 18a and 18b, the length La and width Wa of connecting electrodes 19a and 19b, the areas of the bonding pads 20a and 20b, and the capacitance of capacitor connected electrically to the bonding pads 20a and 20b.

Embodiment 8.

Figs.19, 20 and 21 illustrate the film acoustic wave device for embodiment 8.

A description of the numbered components indicated in figures follows: the wafer 11 made of silicon (Si) conductor; the

film acoustic wave devices 12a~12c; the orientation flat 13 showing the standard surface of wafer 11; a silicon (Si) semiconductor substrate 25; the ground electrode 15; bonding pads 16 at equal electric potential as ground electric potential; the piezoelectric thin film 17 made of lead titanate ($PbTiO_3$); the upper electrodes 18a and 18b; the connecting patterns 19a and 19b; the bonding pads 20a and 20b respectively connected to the upper electrodes 18a and 18b; and the via hole 21.

In Fig.19, within the variables of length Le, width We of upper electrodes 18a and 18b, and distance Lg between upper electrodes 18a and 18b, length La, width Wa of connecting patterns 19a and 19b, and areas of bonding pads 20a and 20b, more than at least one has changed depending on their positions placed on the wafer 11 for film acoustic wave devices 12a~12c. As Figs.8 to 18 are showing, for the film acoustic wave devices 12a~12c, by changing the variables of length Le and width We of upper electrodes 18a and 18b, distance Lg between the upper electrodes 18a and 18b, length La and width Wa of connecting patterns 19a and 19b, the capacitance of capacitor connected electrically to bonding pads 20a and 20b, variation of frequency response from the positioning at the wafer 11 is compensated. From this, even

if thickness distribution is formed on top of the piezoelectric thin film 17 from positioning at the wafer 11, the film acoustic wave device 12 with a less variation of frequency response is obtained.

A semiconductor substrate 14 made of gallium arsenide (GaAs) shown in Fig.1 has a good insulation, and as for a configuration of the film acoustic wave device 12 there is an advantage of minimizing a loss from the semiconductor substrate 14. However, its cost being expensive that it is disadvantaged in terms of manufacturing cost. On the other hand, a semiconductor substrate 25 made of silicon (Si) can be manufactured in massive quantity and expense for the wafer 11 is less. In addition, a radius of the wafer is larger, and when compare a single wafer with the semiconductor substrate 14 made of gallium arsenide (GaAs), the mass production of the film acoustic wave devices 12 is possible, and the manufacturing cost is reduced. Since the area of the wafer 11 is large, a thickness variation of piezoelectric thin film 17 within the wafer 11 becomes large and compensating the variation of frequency response of wafer 11 is important more than the semiconductor substrate 14 made of (GaAs).

Fig.20 is the enlarged view of the film acoustic wave devices

12a, 12b and 12c of Fig.19. Fig.21 is the cross-section B-B of Fig.20. The film acoustic wave device 12 shown in Figs.2 and 3 is using the semiconductor substrate 14, and the film acoustic wave device 12 shown in Figs.20 and 21 is using silicon (Si) semiconductor substrate 25. For such cases the materials being used and all of the dimensions will be same except for the semiconductor substrates itself. Also the equivalent circuit 24 of the acoustic wave filter in Fig.4 is same for both cases, and difference in the element values of capacitors C_{s1}, C_{s2} and C_{i0}, inductor L_{s1} and resistor R_{s1} arises from the different semiconductor materials being used, which also leads to a difference in the frequency response. Therefore, for the film acoustic wave device that uses the silicon (Si) semiconductor substrate 25, when compensating the thickness distribution of the piezoelectric thin film 17 on top of the wafer 11, even if the amount of frequency variation to compensate was same as the film acoustic wave device that uses the gallium arsenide (GaAs) semiconductor substrate 14, the amount of change is different for length Le and width We of upper electrodes 18a and 18b, distance Wa between the electrodes 18a and 18b, length La and width Lg of connecting patterns 19a and 19b, and areas of bonding pads 20a and 20b for the film acoustic wave device 12.

Embodiment 9.

Figs.22, 23 and 24 illustrate the film acoustic wave device for embodiment 9.

A description of the numbered components indicated in the figures follows: the wafer 11 made of gallium arsenide (GaAs) semiconductor; the film acoustic wave devices 12a~12c; the orientation flat 13 showing the standard surface of the wafer 11; the gallium arsenide (GaAs) semiconductor substrate 14; the ground electrode 15; the bonding pad 16 at equal as ground electric potential with the ground electrode 15; the piezoelectric thin film 17 using PZT ($PbTiO_3$-$PbZrO_3$); the upper electrode 18; the connecting pattern 19; the bonding pad 20 connected to the upper electrode 18; and the via hole 21.

Fig.22 is one of the examples which shows change in pattern shape by positioning the film acoustic wave device on top of the wafer 11.

In Fig.22, in a direction parallel to the orientation flat 13, from the central wafer 11 for the film acoustic wave device 12a to the peripheral wafer 11 for the film acoustic wave device 12b has the same shape. Along a direction perpendicular to the orientation flat 13, as approaches the

peripheral wafer 11 of the film acoustic wave device 12c, the bonding pad 20, the width We of upper electrode 18 and the length La of connecting pattern 19 have changed. This is a suitable method for such cases as changing the shape when the thickness distribution of piezoelectric thin film 17 on top of the wafer 11 is mostly uniform in the direction parallel to the orientation flat 13, and is changing the shape in direction perpendicular to the orientation flat 13.

Fig.23 illustrates the bulk acoustic wave resonator of the film acoustic wave device 12 of the present embodiment. The bulk acoustic wave resonator is different from the bulk acoustic wave filter of Fig.2 in that there is only one upper electrode 18. So in this embodiment, the part equivalent to the only one upper electrode 18 is used as the equivalent circuit as in Fig.4. The film acoustic wave device 12 shown in Fig.23 operates as one-port resonator. Unlike the properties of the filter shown in Fig.6, properties of this resonator has a resonant frequency and anti-resonant frequency. Due to this, changes in the thickness of piezoelectric thin film 17 becomes a direct change of the resonant frequency and the anti-resonant frequency. In this type of resonator, the changes in resonant frequency and the anti-resonant frequency are made by connecting the resonator to a reactance device. In the film acoustic wave device 12

shown in Fig.23, the length Le and width We of upper electrode 18 is determines mostly an impedance of the resonator. The connecting pattern 19 and bonding pad 20 are equivalent to the reactance device connected to the resonator. The length La and the width Wa of the connecting pattern 19 and the area of bonding pad 20 determines the element value of reactance connected to the resonator.

Thus, by changing the length La and width Wa of connecting pattern 19 and the area of bonding pad 20, the anti-resonant frequency and the resonant frequency for the resonator is changed. Furthermore, by changing the length Le and width We of upper electrode 18, a relation between the impedance of resonator and a value of the impedance of reactance connected to the resonator is changed. Similar to cases in Figs.10 to 18, by changing the length Le and width We of upper electrodes 18, length La and width Wa of connecting patterns 19, and area of bonding pad 20, the anti-resonant frequency and the resonant frequency of the resonator are changed. There is also the same effect from changing the capacitance of capacitor connected electrically to the bonding pad 20 and changing the area of bonding pad 20.

Embodiment 10.

Fig.25 illustrates the piezoelectric thin film for

embodiment 10.

Fig.26 is an enlarged view of the film acoustic wave device of Fig.25. Fig.27 is a cross-sectional view B-B of Fig.26.

A description of the numbered components indicated on the figures follows: the wafer 11 made of silicon (Si) semiconductor; the film acoustic wave devices 12a~12c; the orientation flat 13 showing standard surface of the wafer 11; the silicon (Si) semiconductor substrate 25; the ground electrode 15; the bonding pad 16 in equal electric potential with the ground electrode 15; the piezoelectric thin film 17 made of zinc oxide (ZnO); the upper electrodes 18a and 18b; the connecting patterns 19a and 19b; the bonding pads 20a and 20b respectively connected to the upper electrodes 18a and 18b; an etching hole 26; a dielectric thin film 27; and a hole 28.

In Fig.25, for the central wafer 11 of film acoustic wave device 12a, going away from the central wafer 11 concentrically, the shape of film acoustic wave device is changed, for example, the length Le of upper electrodes 18a and 18b, and the distance Lg between upper electrodes are changed similarly to the case of peripheral wafer 11 parallel to the direction of orientation flat 13 for the film acoustic

wave device 12b, and the peripheral wafer 11 perpendicular to the direction of orientation flat 13 for the film acoustic wave device 12c. For such central wafer 11, most suitable case to apply the method of changing the shape of film acoustic wave device concentrically is when the thickness of piezoelectric thin film 17 varies concentrically.

To the film acoustic wave device 12 shown in Figs.26 and 27, the hole 28 located beneath the ground electrode 15 is made from frontal side of the upper electrodes 18a and 18b, by opening the etching hole 26 on the dielectric thin film 27 and removing part of the silicon (Si) semiconductor substrate 25 by an anisotropic etching from the etching hole 26. The acoustic resonance of film acoustic wave device 12 is satisfied with this air layer underneath the ground electrode 15. The method of opening the etching hole 26 via hole 21 can be made from the front as shown in Fig.27 or from the back as shown in Fig.24. In any which way, the properties of the film acoustic wave device 12 remain the same. Furthermore, in Fig.27, between the semiconductor substrate 25 and ground electrode 15, there is the dielectric thin film 27, however, although it is omitted in the drawings of Figs.21 and 24, there are the dielectric thin films 27 for the actual film acoustic wave device 12.

Embodiment 11.

Fig.28 illustrates the film acoustic wave device for embodiment 11.

Fig.29 is the enlarged diagram shown in Fig.28. Fig.30 is the cross-sectional view B-B of Fig.29.

A description of the numbered components indicated in the figures follows: the wafer 11 made of gallium arsenide (GaAs) semiconductor substrate; the film acoustic wave devices 12a ~12c; the orientation flat 13 showing the standard surface of the wafer 11; the gallium arsenide (GaAs) semiconductor 14; the ground electrode 15; the bonding pads 16 in equal electric potential to the ground electrode 15; the piezoelectric thin film 17 made of aluminum nitride (AlN); the upper electrodes 18a and 18b; the connecting patterns 19a and 19b; the bonding pads 20a and 20b respectively connected to the upper electrodes 18a and 18b; the hole 28, a second electrode 29a that is not connected electrically to upper electrode 18a; and a second electrode 29b that is not electrically connected to 18b.

In Fig.28 of the present embodiment, length Le2 of the second electrodes 29a and 29b, and distance Lg2 between the upper electrode 18a and the second electrode 29a are changed. The

distance Lg2 is also a distance between the second electrode 29b and the upper electrode 18b. As opposed to central part of the wafer 11 of the film acoustic wave device 12a, in the direction parallel to the orientation flat 13, as approach closely to the peripheral wafer 11 of the film acoustic wave device 12b, distance Lg2 between the second electrode 29a and upper electrode 18a (also the distance Lg2 between the second electrode 29b and the upper electrode 18b) are changed. In the direction perpendicular Lg2 to the orientation flat 13, as approach the peripheral wafer 11 of the film acoustic wave device 12c, the distances between the upper electrodes 18a and 18b with the second electrodes 29a and 29b, and length Le2 of the second electrodes 29a and 29b are changed. Such method, for example, can be adopted not only when the thickness h of the piezoelectric thin film 17 is distributed, but also when the change in properties of the film acoustic wave device at the wafer 11 are differing at direction parallel and direction perpendicular to the orientation flat, due to the change in the component ratio of materials which the piezoelectric thin film 17 is being made of. For instance, in the direction parallel to the orientation flat 13, the passband of film acoustic wave device 12b changes and in the direction perpendicular to the orientation flat 13, the passband and the band width of the film acoustic wave device 12c are changed, and in direction parallel to the orientation

flat 13, passband of the film acoustic wave device 12b is compensated, and in the perpendicular direction both band width and passband of the film acoustic wave device 12c need be compensated, and need to change the way to change the forms of film acoustic wave device in directions parallel and perpendicular to the orientation flat 13.

Fig.29 is the enlarged view of the film acoustic wave devices 12a, 12b and 12c of Fig.28. Fig.30 is cross-section B-B of Fig.29.

The hole 28 is made without etching the gallium arsenide (GaAs) semiconductor substrate 14 on the lateral side of ground electrode 15. In this case, the properties of bulk acoustic wave filter is almost exactly same as the case of etching the gallium arsenide (GaAs) semiconductor substrate 14.

Embodiment 12.

Figs.31, 32 and 33 illustrate the acoustic wave for embodiment 12.

A description of the numbered components indicated on the figures follows: the wafer 11 made of silicon (Si) semiconductor; the film acoustic wave devices 12a~12c; the

orientation flat 13 showing standard surface of the wafer 11; the silicon (Si) semiconductor substrate 25; the ground electrode 15; the bonding pads 16 at equal electric potential with the ground electrode 15; the piezoelectric thin film 17 made of lead titanate ($PbTiO_3$); the upper electrode of input side 18a; the upper electrode of output side 18b; the connecting patterns 19a and 19b; the bonding pads 20a and 20b connected respectively to the upper electrodes 18a and 18b; the second electrodes 29a and 29b that are not electrically connected to the upper electrodes 18a and 18b as in embodiment 11; a third electrode 30 that are not electrically connected to the upper electrodes 18a and 18b; an inductor 31; an electrode of capacitor 32; a connecting electrode 33 which electrically connects bonding pad 20a to the electrode of capacitor 32; and a dielectric substance layer 34 made of multi-layer of materials with various acoustic properties which function similarly to the hole 28.

In Figs.31 to 33 of the present embodiment, an area of the capacitor electrode 32 is changed depending on the positioning at wafer 11. Resulting in approximately same effect as changing the capacitor C_{S1} of the equivalent circuit in Fig.4 the variation in property of the film acoustic wave device 12 on top of the wafer 11 is compensated.

Fig.32 is the enlarged view of the film acoustic wave devices 12a, 12b and 12c of Fig.31. The third electrode 30 is placed in between the upper electrode of input side 18a and the upper electrode of output side 18b.

Fig.33 is the cross-section B-B of Fig.32.

In between the bonding pad of an input side 20a and the bonding pad of a connecting side 16, a capacitor comprising the inductor 31 and the capacitor electrode 32 is electrically connected in parallel with the connecting electrode 33. In Fig.32 only the bonding pad of input side 20a is connected to the capacitor, however, the bonding pad of output side 20b can also be connected similarly. It is possible to change at least either one of the length Le3 of the third electrodes 30 and the distance Lg3 between the third electrodes 30 and the upper electrodes 18a and 18b.

For property variations that occurs at the wafer 11, for example, a resonant frequency variation caused from the thickness distribution of the piezoelectric thin film 17, the resonant frequency can be compensated by changing the pattern shape of the film acoustic wave device 12, depending on the position at the wafer 11, to obtain the film acoustic wave devices with the same properties that does not depend

on the positioning at wafer 11.

As such, when changing the pattern for the film acoustic wave device 12, there is a limit to an extent of the compensation. This limit varies with the type of piezoelectric thin film 17, type of upper electrodes 18a and 18b, type of ground electrode 15, type of dielectric film 27, thickness of piezoelectric thin film 17, thickness of upper electrodes 18, 18a and 18b, thickness of ground electrode 15, thickness of dielectric film 27 being used in the film acoustic wave device 12, and the pattern of film acoustic wave device. Especially the type of piezoelectric thin film 17 is a major factor limiting the extent of compensation. In general, a larger the electrochemical coupling factor of the piezoelectric thin film 17, the greater the extent of compensation. The electromechanical coupling constant has a large correlation with equivalent voltage coefficient e in the calculation examples of Figs.6 to 18.

For use in the piezoelectric ceramics with lead, materials such as lead titanate ($PbTiO_3$) and PZT ($PbTiO_3$-$PbZrO_3$) show excellent properties of the electromechanical coupling constant. In addition, these type of piezoelectric ceramics with lead are formed under a high temperature when making the thin film, therefore, the ceramics has a high melting

point that it is essential to use chemically stable elements such as platinum (Pt) or gold (Au) for the ground electrode 15, and gallium arsenide (GaAs) semiconductor substrate and silicon (Si) semiconductor substrate as the substrate. Especially, Platinum (Pt) is excellent in the chemical stability. Lead titanate ($PbTiO_3$) is excellent material for Q, especially so as a material for a device that pre-conditions the use high frequency greater than GHz such as the film acoustic wave device. On the other hand, compared to other materials as zinc oxide (ZnO) or aluminum nitride (AlN), due to numerous type of material compositions, it is difficult to form the film with uniform composition throughout the wafer 11, that it becomes very important to compensate for property variation throughout the wafer 11. Using the PZT($PbTiO_3$-$PbZrO_3$), the piezoelectric thin film 17 can have various properties by changing the ratio of constituents of lead titanate ($PbTiO_3$) and lead titanate-zirconate ($PbZrO_3$). A larger value of electromechanical coupling constant can be obtained using the PZT($PbTiO_3$-$PbZrO_3$) compared to just the lead titanate ($PbTiO_3$). Such type of piezoelectric thin film has a greater advantage upon designing. However, since the PZT($PbTiO_3$-$PbZrO_3$) includes a numerous type of material compositions more than the lead titanate ($PbTiO_3$), it becomes

difficult to form a film uniformly, and the compensation for variation property throughout wafer 11 is important.

The electromechanical coupling constant of the piezoelectric ceramics that does not contain lead such as zinc oxide (ZnO) and aluminum nitride (AlN) are inferior to the piezoelectric ceramics with lead. However, they are characterized by a large value of Q. The large value of Q is ideal for a narrow band filter when configuring the filter. When the thickness of piezoelectric thin film 17 changes throughout the wafer 11 even slightly, the narrow band filter results in the lag of passband from the necessary area. It is important to compensate the thickness distribution of the piezoelectric thin film 17 throughout the wafer 11, especially important to compensate the property variations inside the wafer 11. Also, this type of piezoelectric ceramics that does not contain lead, a forming temperature of the piezoelectric thin film is relatively low. It is possible for this type of the piezoelectric ceramics to use the glass substrate other than semiconductor substrates such as gallium arsenide (GaAs) or silicon (Si). It is also possible for this type of piezoelectric ceramics to use the ground electrode 15 other than platinum (Pt) or gold (Au), and even possible to use materials with low melting point such as aluminum (Al).

The film acoustic wave device 12 has illustrated a multiple number of combinations of parameters namely: upper electrode 18, 18a and 18b; distance Lg between the upper electrode of input side 18a and upper electrode of output side 18b; length La and width Wa of connecting patterns 19, 19a and 19b; area of bonding pads 20, 20a, 20b; area of capacitor electrode 32 connected electrically to bonding pads 20a and 20b; length Le2 of second electrode 29a and 29b; distance Lg2 between second electrodes 29a and 29b to upper electrodes 18a and 18b; length Le3 of third electrode 30; distance Lg3 between the third electrode and upper electrodes 18a and 18b. With these examples, as shown in Figs.8 to 18, changing one of the parameters is sufficient for the compensation.

On the other hand, there are effective combinations of parameters that are not illustrated in the embodiments. The parameters are: length Le and width We of upper electrodes 18, 18a and 18b; distance Lg between the upper electrode of input side 18a and the upper electrode of output side 18b; length La and width Wa of connecting patterns 19, 19a and 19b; area of bonding pads 20a and 20b; area of capacitor electrode 32 connected electrically to bonding pads 20a and 20b; length Le2 of second electrodes 29a and 29b; distance Lg2 between the second electrodes 29a and 29b with upper

electrodes 18a and 18b; length Le3 of third electrode 30; distance Lg3 between the third electrodes 18a and 18b. That is, for optional combinations within these parameters, variation can be compensated at the top of wafer 11.

In embodiments of the present invention, pattern of the film acoustic wave devices shown in the Figs.7,9,11,13,15, 17,19,20,22,23,25,26,28,29,31 and 32 are some of the examples. There is no requirement to limit the pattern, and the pattern change to influence the property of film acoustic wave device is selective.

Moreover, there is no need to limit the cross-sectional shape of film acoustic wave device to those shown on Figs.21,24, 27,30 and 33. For example, bulk acoustic wave resonator shown in Fig.23 is used as series and parallel elements of a ladder filter. In this case, the same effect can be obtained. The same effect will also be obtained by any combinations of cross-sectional shapes of film acoustic wave devices shown in Figs.21,24,27,30 and 33, and shapes of pattern of the film acoustic wave devices shown in Figs.7,9,11,13,15,17,19,20,22,23,25,26,28,29,31 and 32.

In previously described embodiments, within the pattern shape of film acoustic wave device, length Le and width We

of upper electrodes 18, 18a and 18b; length La and width Wa of connecting patterns 19, 19a and 19b; area of bonding pads 20a and 20b; area of capacitor electrode 32 connected electrically to bonding pads 20a and 20b; length Le2 of second electrode 29a and 29b; distance Lg2 betwen second electrode 29a and 29b and upper electrodes 18a and 18b respectively; and distance Lg3 between the third electrode and upper electrodes 18a and 18b respectively, in order to change these parameters by the positioning at the top of the wafer, the example is given for one of an element a or b to change in equal amount the parameters mentioned above, however, for one of the elements a or b, the parameters can be changed in different amount. This means, for example, not only to change the length Le of upper electrodes 18a and 18b by position of the film acoustic wave device at the wafer 11, but also to make the length Le of upper electrode 18a and length Le of upper electrode 18b different of one film acoustic wave device. Another example, not only to change the distance Lg2 between the second electrode 29a and 29b and upper electrode 18a and 18b by position of the film acoustic wave device at wafer, but also to make the distance Lg2 between the second electrode 29a and upper electrode 18a different to the distance Lg2 between the upper electrode 18b and the second electrode 29b of one film acoustic wave device.

As such, by changing the parameters differently rather than changing the parameters equally, the extent of compensation is extended.

Industrial Applicability

According to the present invention, by changing at least more than one of the pattern of film acoustic wave device, such as the length Le or width We of upper electrodes, the distance Lg between the upper electrodes of input/output side, the length La and width Wa of connecting pattern, the areas of bonding pads, the areas of electrode of capacitor connected electrically to bonding pads by the positioning at wafer, a variation of property for the film acoustic wave device that arises when positioning at wafer is reduced, and the film acoustic wave device with same properties that are not affected by the wafer positioning is obtained.

Without limiting the thickness of piezoelectric thin film, the type of materials for the film acoustic wave device or its combination, a variety of acoustic wave device that are useful in industries is achieved.

What is claimed is:

1. A film acoustic wave device comprising: a wafer made of a semiconductor substrate; a ground electrode formed on top of the semiconductor substrate; a piezoelectric thin film formed on top of the ground electrode; and an upper electrode formed on top of the piezoelectric thin film, wherein a pattern shape for the film acoustic wave device is changed by a position at the wafer.

2. The film acoustic wave device according to claim 1, wherein a length of the upper electrode is changed by the position at the wafer.

3. The film acoustic wave device according to claim 1, wherein a width of the upper electrode is changed by the position at the wafer.

4. The film acoustic wave device according to claim 1, wherein the upper electrode includes a plurality of upper electrodes, wherein distances between the upper electrodes are changed by the position at the wafer.

5. The film acoustic wave device according to claim 1 further comprising a bonding pad for connecting with the

upper electrode, wherein a shape of the bonding pad is changed by the position at the wafer.

6. The film acoustic wave device according to claim 5 further comprising a connecting pattern for connecting the upper electrode with the bonding pad, wherein a shape of the connecting pattern is changed by the position at the wafer.

7. The film acoustic wave device according to claim 6, wherein the connecting pattern forms an air bridge.

8. The film acoustic wave device according to claim 1 further comprising a capacitor provided on the same semiconductor substrate as the film acoustic wave device, wherein a capacitance of the capacitor is changed by the position of the wafer.

9. The film acoustic wave device according to claim 1, wherein the semiconductor substrate is made of gallium arsenide (GaAs); the piezoelectric thin film is made of lead titanate ($PbTiO_3$); and at least one of the upper electrode is a conductor substantially made of platinum (Pt).

10. The film acoustic wave device according to claim 1, wherein the a semiconductor substrate is made of silicon

(Si); the piezoelectric thin film is made of lead titanate ($PbTiO_3$); and at least one of the upper electrode is a conductor substantially made of platinum (Pt).

11. The film acoustic wave device according to claim 1, wherein the piezoelectric thin film is made of PZT($PbTiO_3$-$PbZrO_3$); and at least one of the upper electrode and the ground electrode is a conductor substantially made of platinum (Pt).

12. The film acoustic wave device according to claim 1, wherein the piezoelectric thin film is made of zinc oxide (ZnO).

13. The film acoustic wave device according to claim 1, wherein the piezoelectric thin film is made of aluminum nitride (AlN).

14. The film acoustic wave device according to claim 1 further comprising an inductor between the semiconductor substrate and the ground electrode.

15. A circuit device comprising: a substrate; and a plurality of elements formed on the substrate, wherein the pattern shape of the elements formed on the substrate is

changed by a position at the substrate.

16. A manufacturing method of the film acoustic wave device comprising steps of:

(a) forming a ground electrode on top of a wafer made of a semiconductor substrate;

(b) forming a piezoelectric thin film on top of the ground electrode;

(c) forming an upper electrode on top of the piezoelectric thin film; and

(d) changing a pattern shape of the upper electrode formed on top of the piezoelectric thin film by the position at the wafer.

17. The manufacturing method of the film acoustic wave device according to claim 16, wherein the step of changing the pattern shape includes a step of changing the length of the upper electrode by the position at the wafer.

18. The manufacturing method of the film acoustic wave device according to claim 16, wherein the step of changing the pattern shape includes a step of changing the width of the upper electrode by the position at the wafer.

19. The manufacturing method of the film acoustic wave

device according to claim 16, wherein the step of forming the upper electrode forms a plurality of upper electrodes, and wherein the step of changing the pattern shape includes a step of changing the distance between the upper electrodes by the position at the wafer.

20. The manufacturing method of film acoustic wave device according to claim 16, and wherein the step of forming the upper electrode further includes a step of connecting of the upper electrode to a bonding pad, and wherein the step of changing the pattern shape includes a step of changing a shape of the bonding pad by the position at the wafer.

21. The manufacturing method of the film acoustic wave device according to claim 20, wherein the step of forming the upper electrode further includes the connecting the upper electrode and the bonding pad to a connecting pattern, and wherein the step of changing the pattern shape includes a step of changing a shape of the connecting pattern by the position at the wafer.

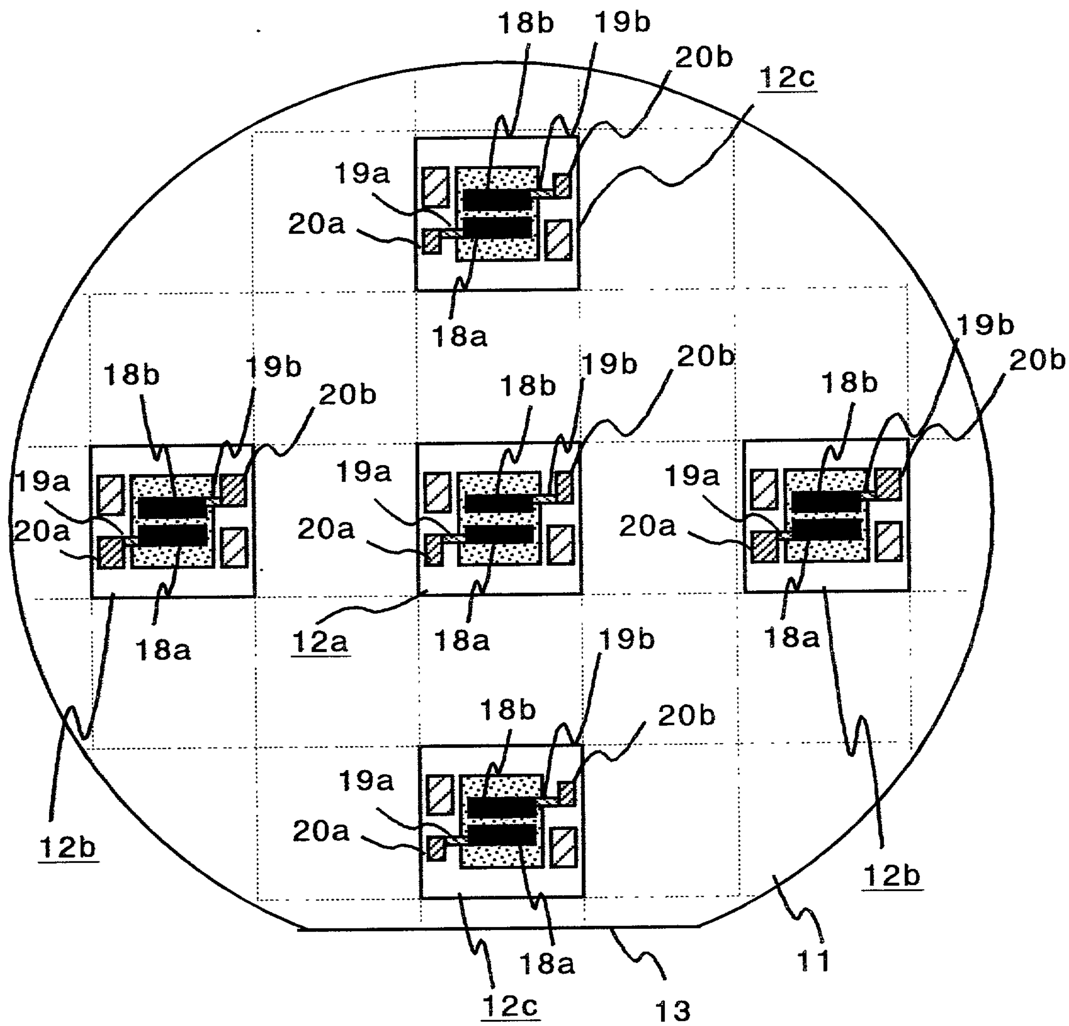
22. The manufacturing method of the film acoustic wave device according to claim 21, wherein the step of changing the pattern shape includes a step of forming the connecting pattern with the air bridge.

23. The manufacturing method of the film acoustic wave device according to claim 16 further comprising a step for setting a capacitor on the same semiconductor substrate as the film acoustic wave device, and wherein the step of changing the pattern shape includes a step of changing a capacitance of the capacitor by the position at the wafer.

ABSTRACT

The film acoustic wave devices (12a, 12b and 12c) having the same properties are obtained by changing at least one of the followings: the length and/or the width of upper electrode (18a and 18b); the distance between the upper electrodes (18a and 18b); the length and/or the width of connecting patterns (19a and 19b); areas of bonding pads (20a and 20b); and the pattern shape for the film acoustic wave device (12a and 12b) such as the area of capacitor electrode connected electrically to the bonding pads (20a and 20b); the property variations of film acoustic wave devices (12a, 12b and 12c) caused from the positioning at wafer 11 is compensated.

Fig. 1


18b
19b
20b
12c
19a
20a
18a
18b
19b
20b
18b
19b
20b
18b
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19a
20a
19a
20a
19a
20a
18a
12a
18a
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19b
18b
20b
19a
20a
12b
12b
18a
11
12c
13

Fig.2

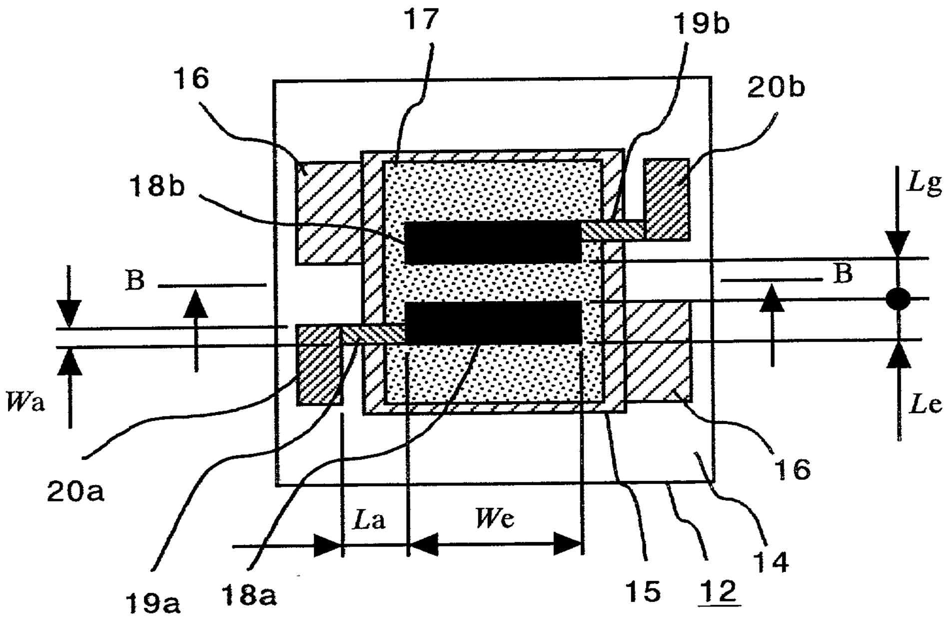

17
19b
16
20b
18b
Lg
B
B
Wa
Le
20a
16
La
We
14
19a
18a
15
12

Fig.3

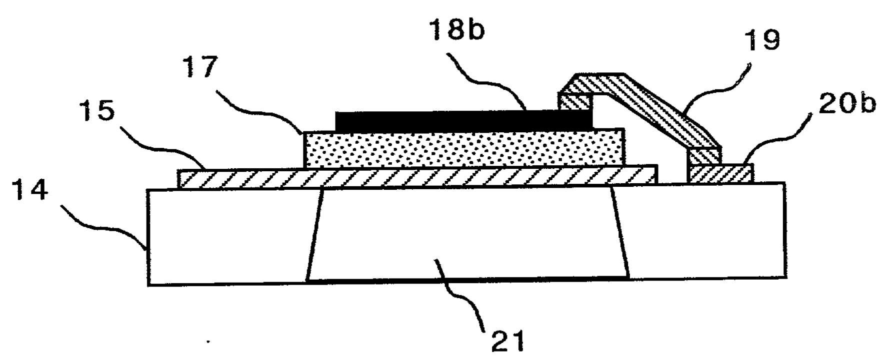
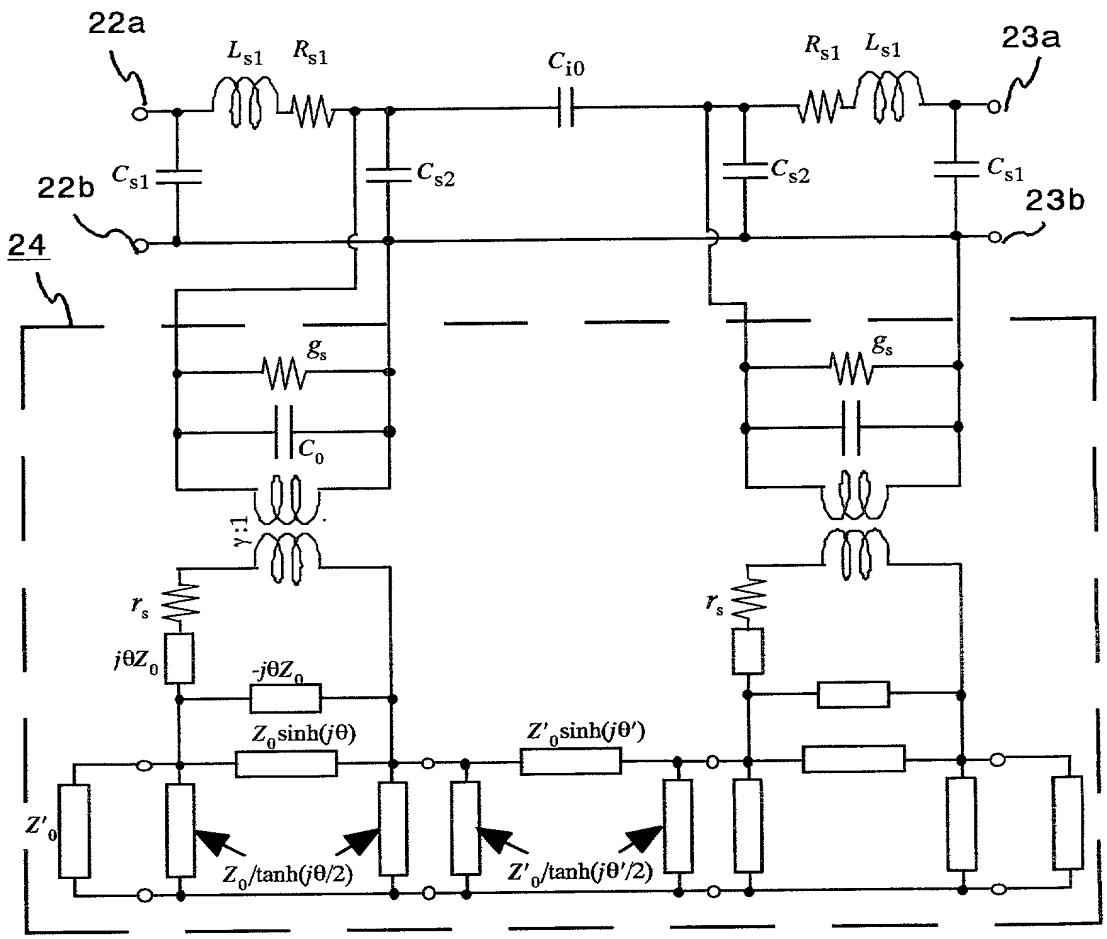

18b
19
17
20b
15
14
21

Fig.4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L_{s1}
R_{s1}
C_{i0}
R_{s1}
L_{s1}
23a
22b
C_{s1}
C_{s2}
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C_{s1}
23b
24
g_s
C_0
g_s
γ:1
r_s
$j\theta Z_0$
$-j\theta Z_0$
r_s
$Z_0\sinh(j\theta)$
$Z'_0\sinh(j\theta')$
Z'_0
$Z_0/\tanh(j\theta/2)$
$Z'_0/\tanh(j\theta'/2)$

Fig.5

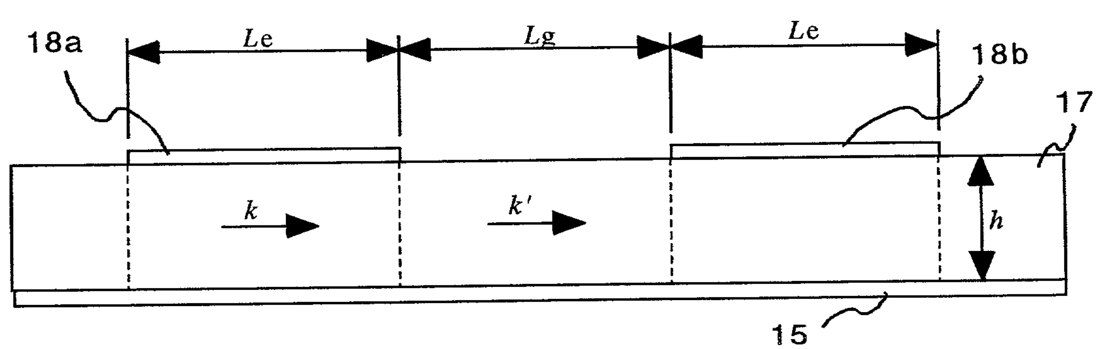
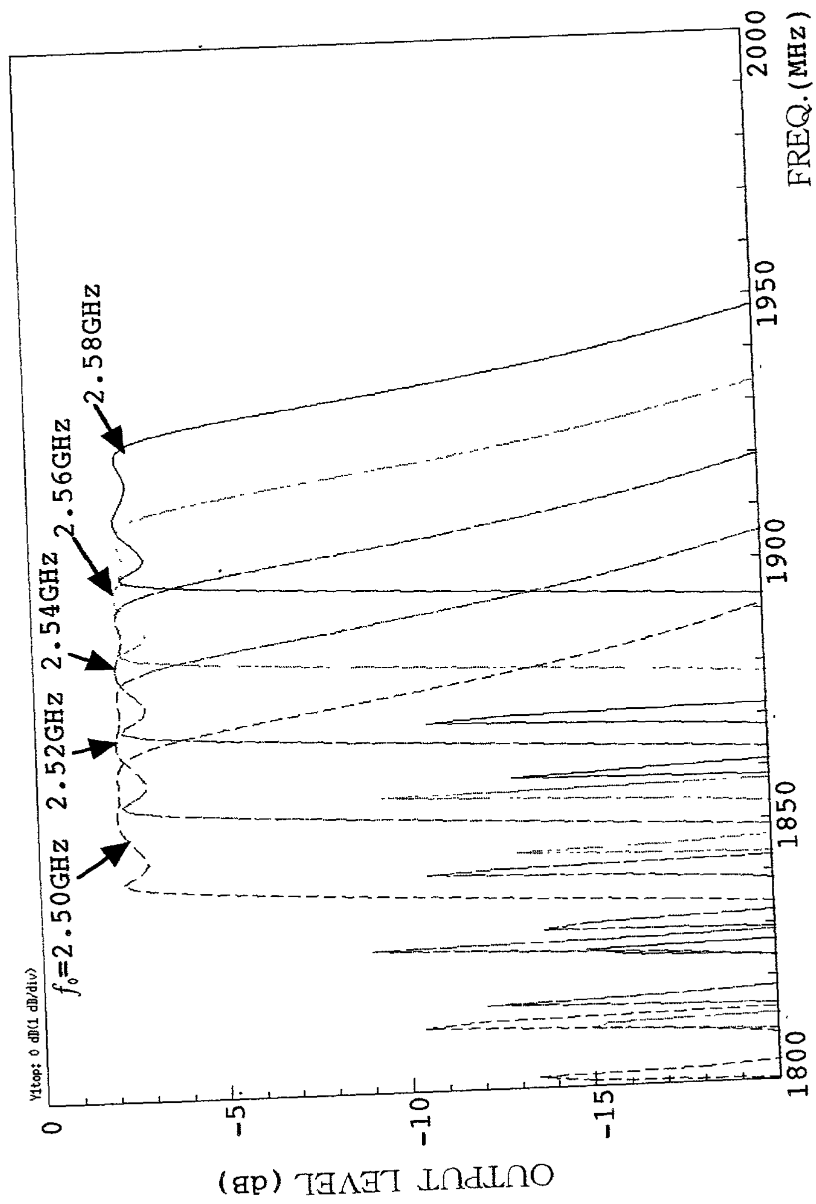

18a
Le
Lg
Le
18b
17
k
k'
h
15

Fig.6


f_0=2.50GHz
2.52GHz
2.54GHz
2.56GHz
2.58GHz
FREQ.(MHz)
1800
1850
1900
1950
2000
OUTPUT LEVEL (dB)
0
-5
-10
-15
Y1top: 0 dB(1 dB/div)

09/202070

Fig.7

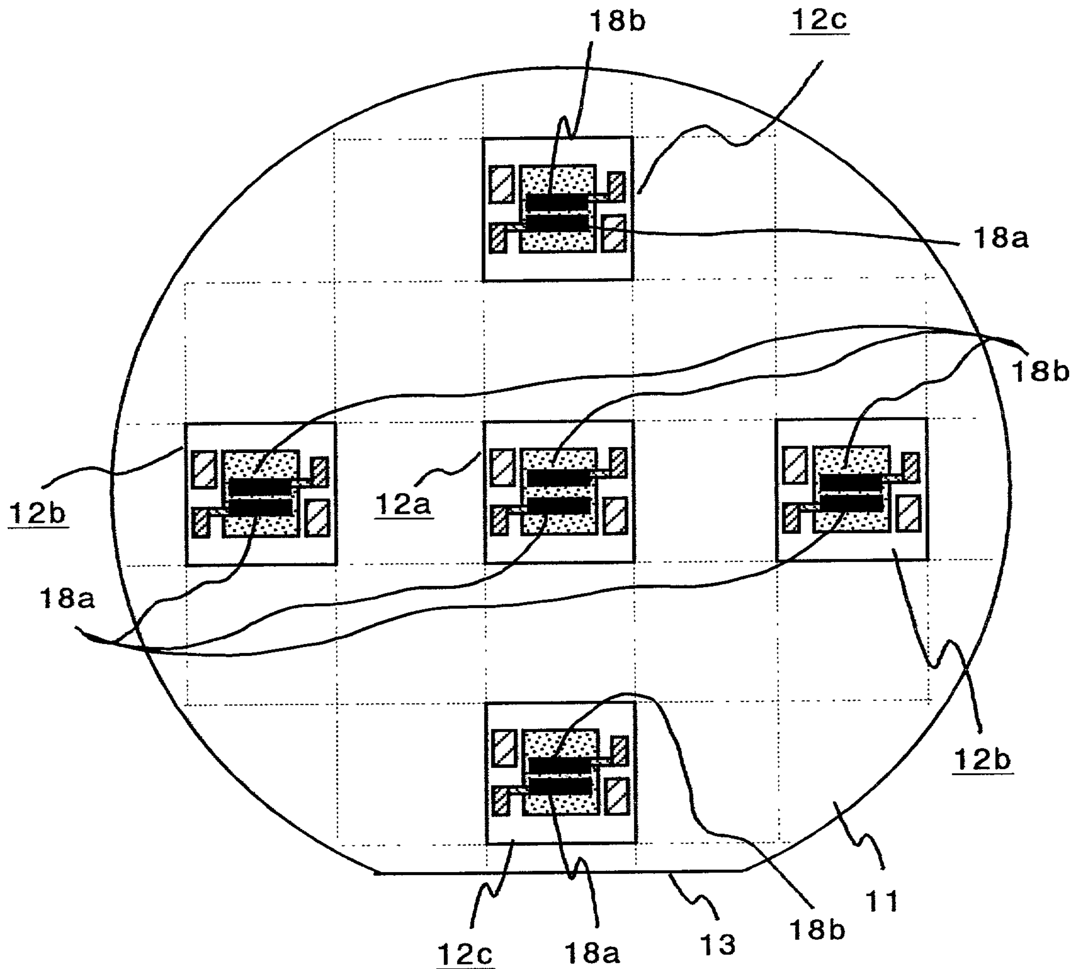


Fig.8

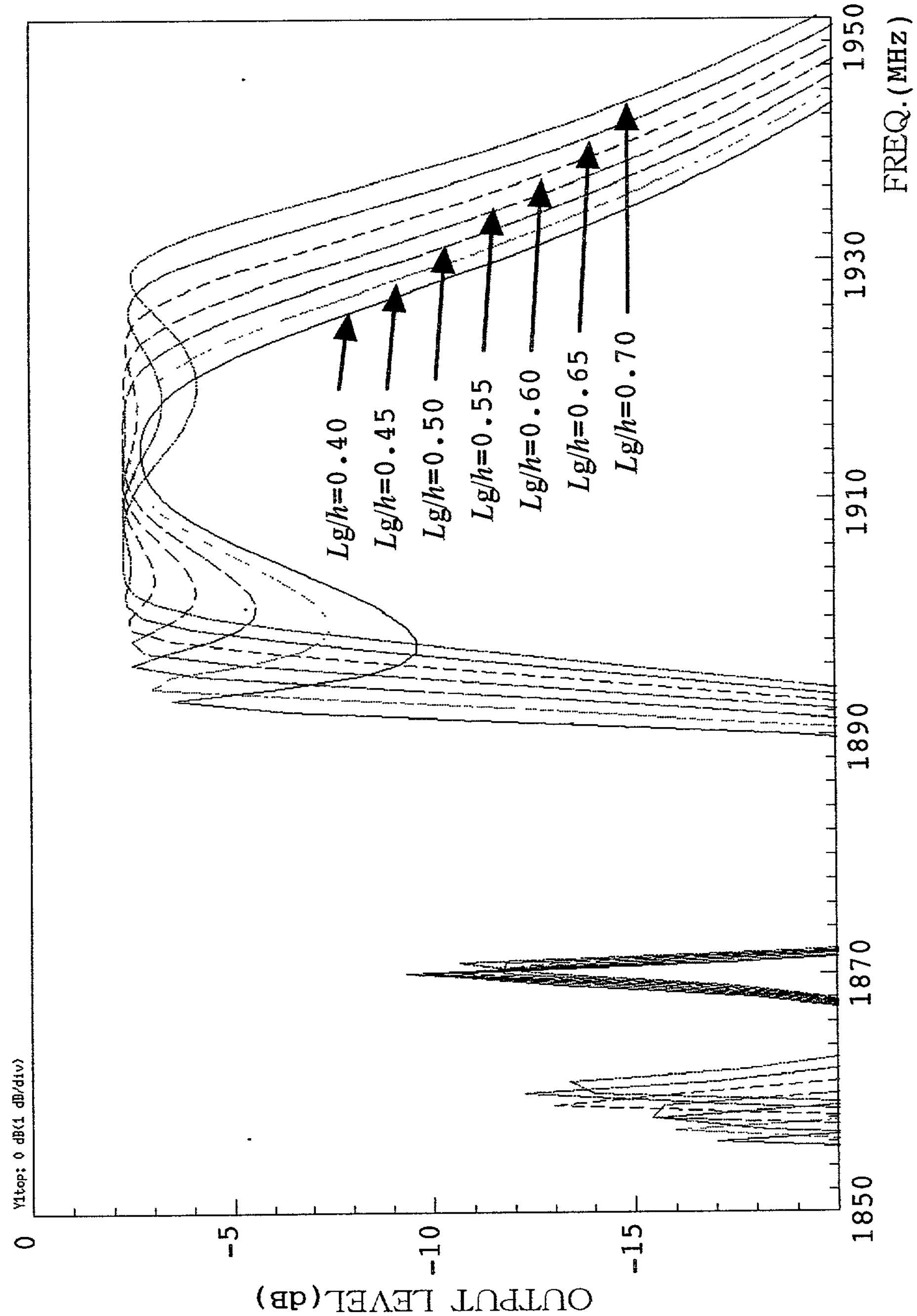

Y1top: 0 dB(1 dB/div)
OUTPUT LEVEL(dB)
0
-5
-10
-15
FREQ.(MHz)
1850
1870
1890
1910
1930
1950
Lg/h=0.40
Lg/h=0.45
Lg/h=0.50
Lg/h=0.55
Lg/h=0.60
Lg/h=0.65
Lg/h=0.70

Fig.9

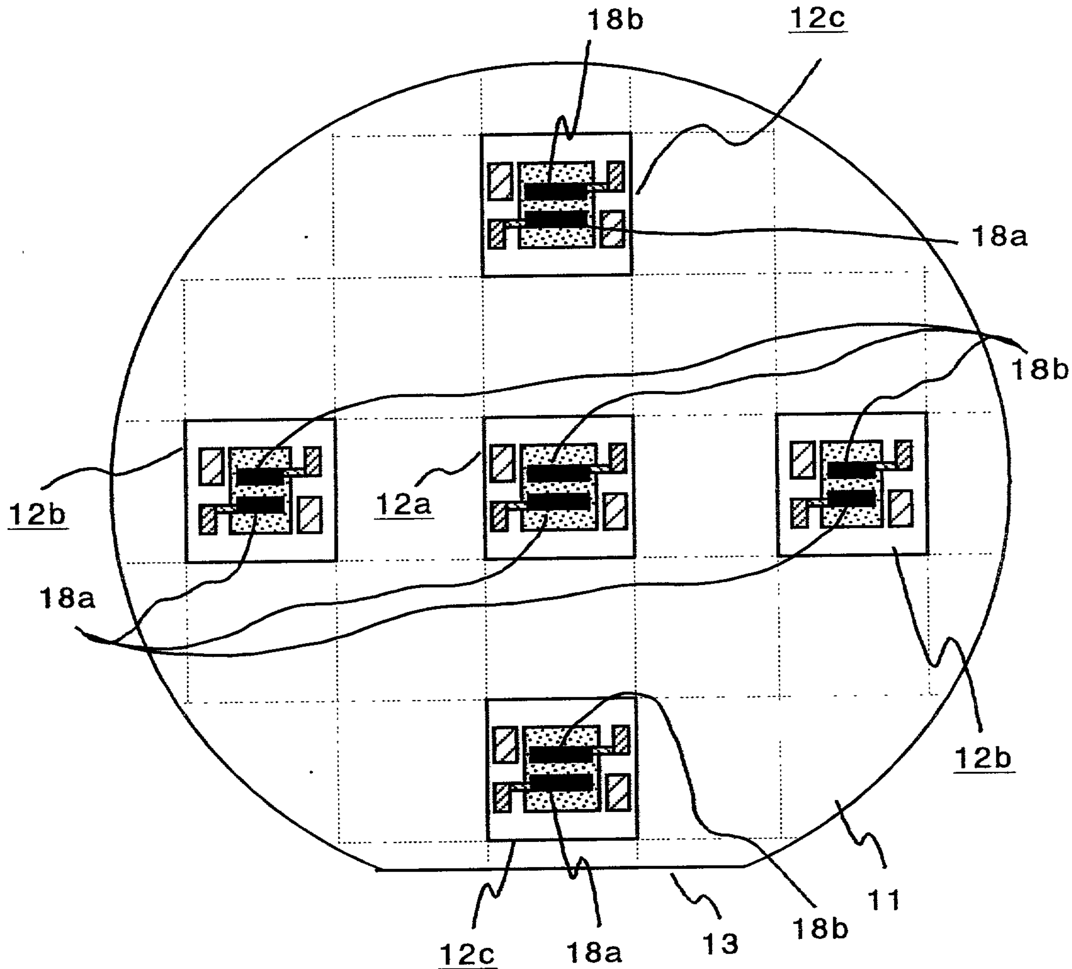


Fig.10

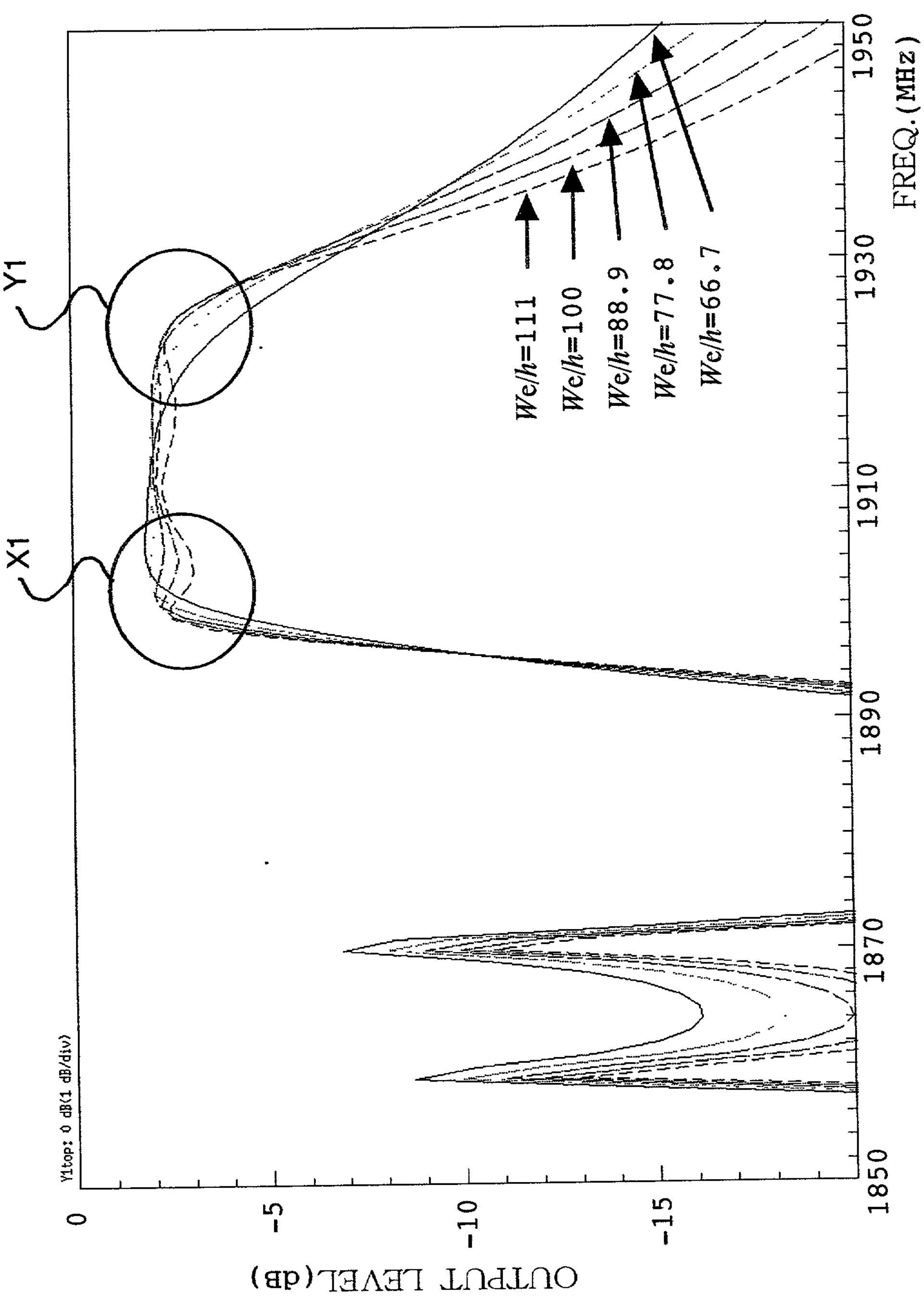

X1
Y1
We/h=111
We/h=100
We/h=88.9
We/h=77.8
We/h=66.7
Y1top: 0 dB(1 dB/div)
FREQ.(MHz)
1850
1870
1890
1910
1930
1950
OUTPUT LEVEL(dB)
0
-5
-10
-15

Fig.11

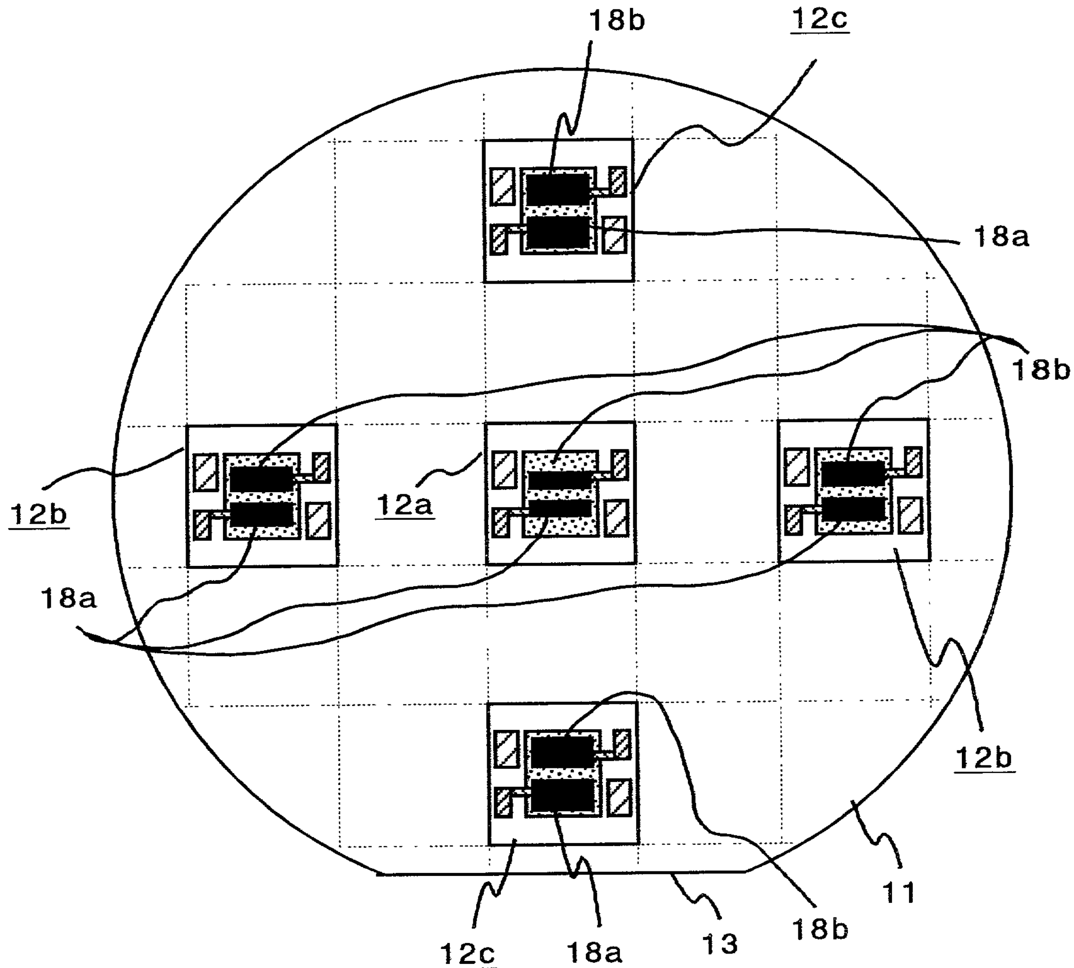
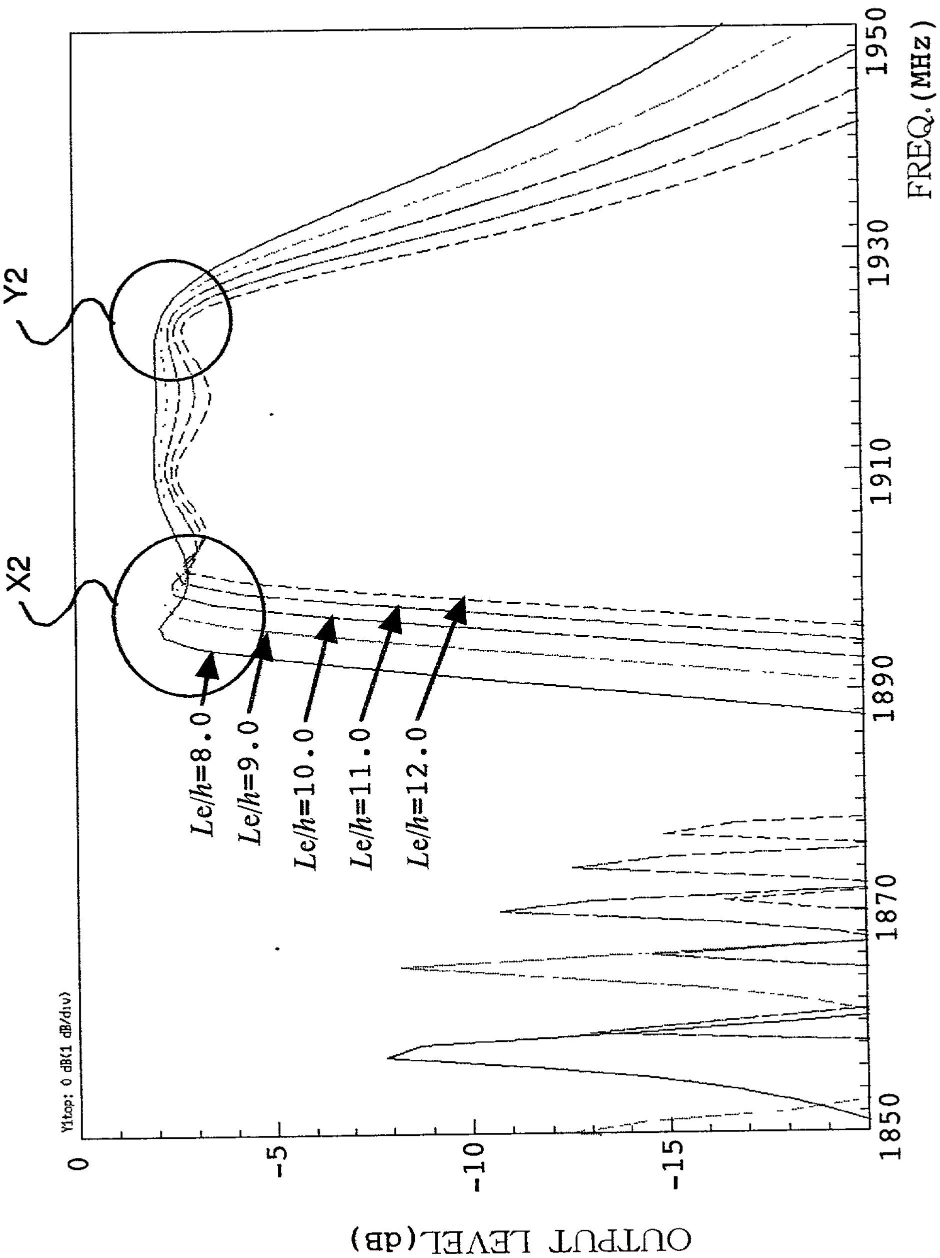
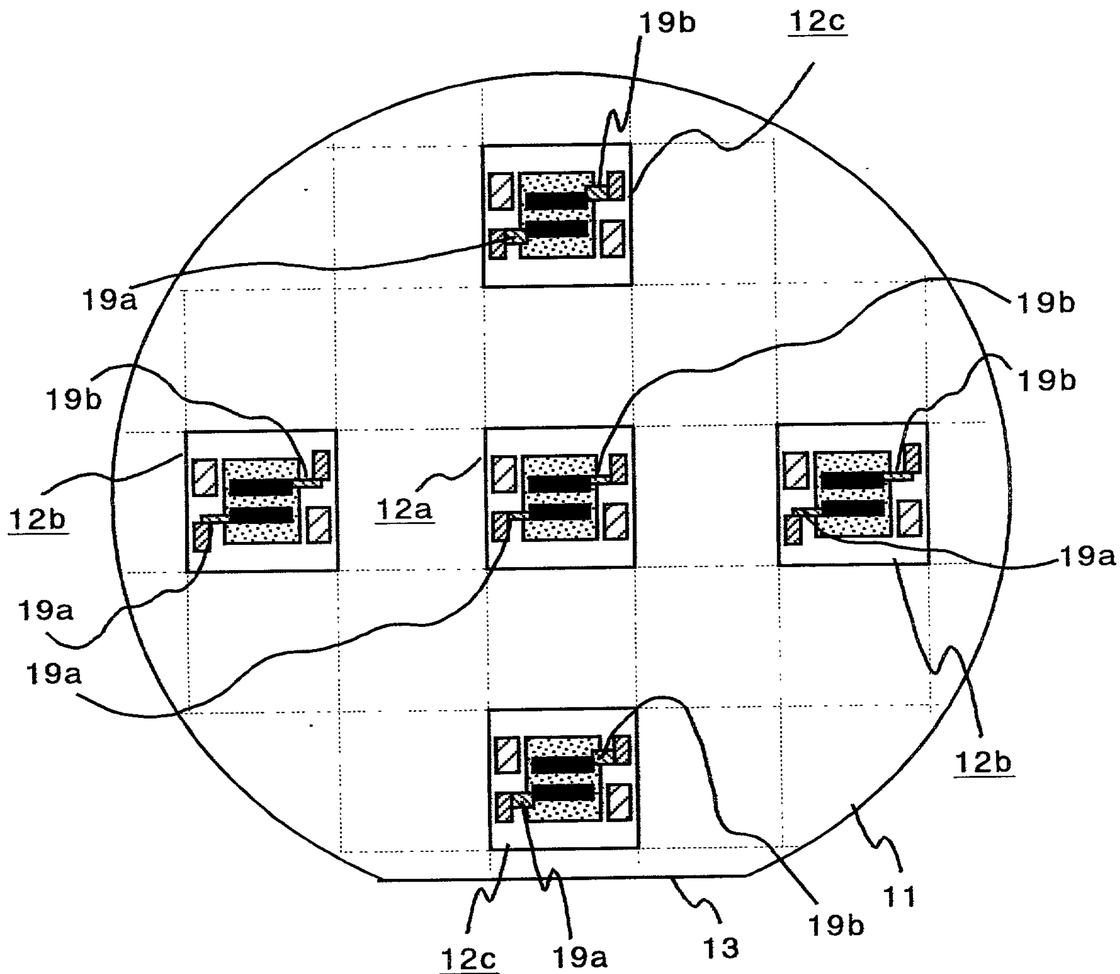


Fig.12



Y2
X2
Le/h=8.0
Le/h=9.0
Le/h=10.0
Le/h=11.0
Le/h=12.0
Y1top: 0 dB(1 dB/div)
0
-5
-10
-15
OUTPUT LEVEL(dB)
1850
1870
1890
1910
1930
1950
FREQ.(MHz)

Fig.13



09/202070

Fig.14

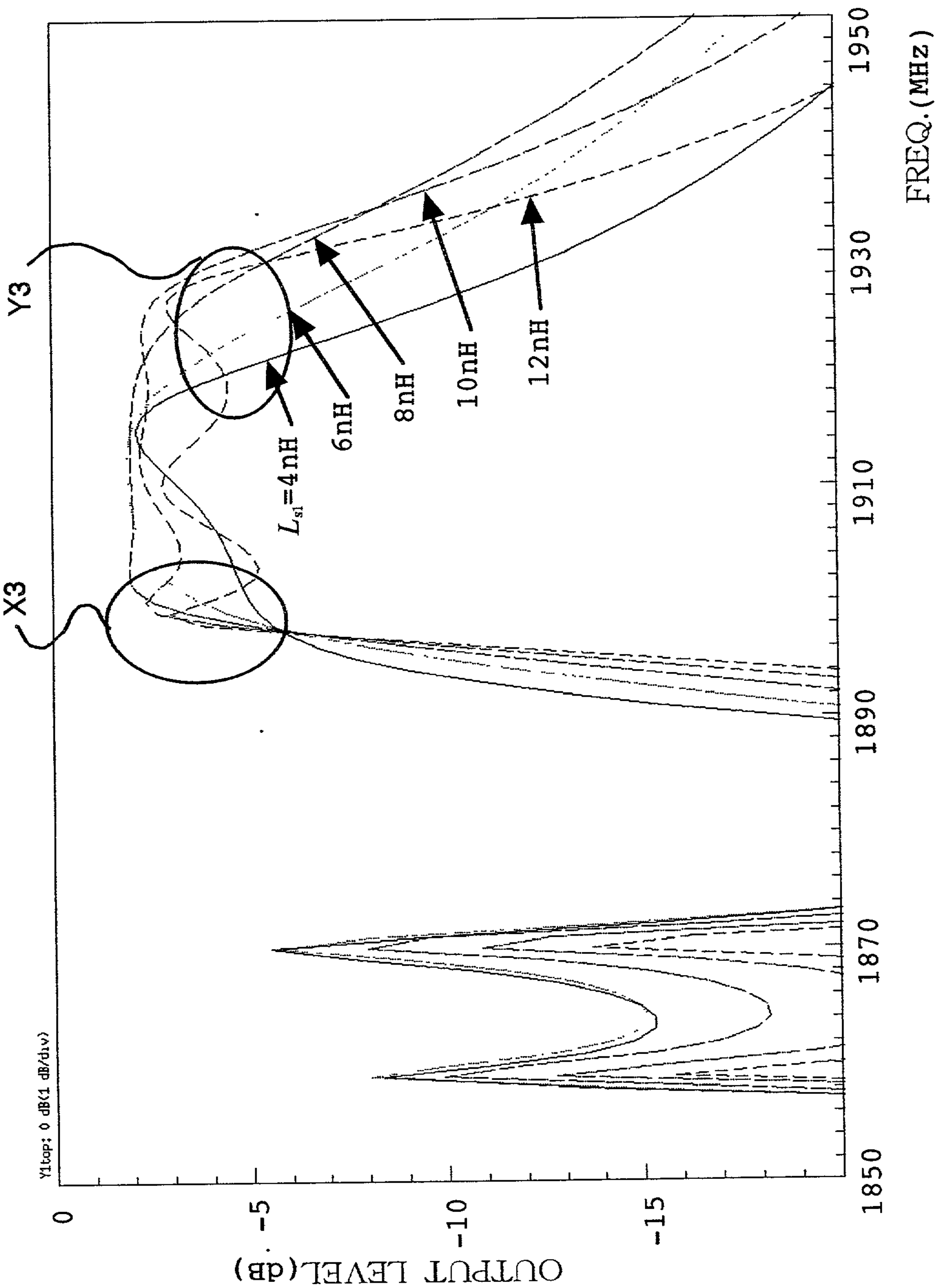


Fig.15

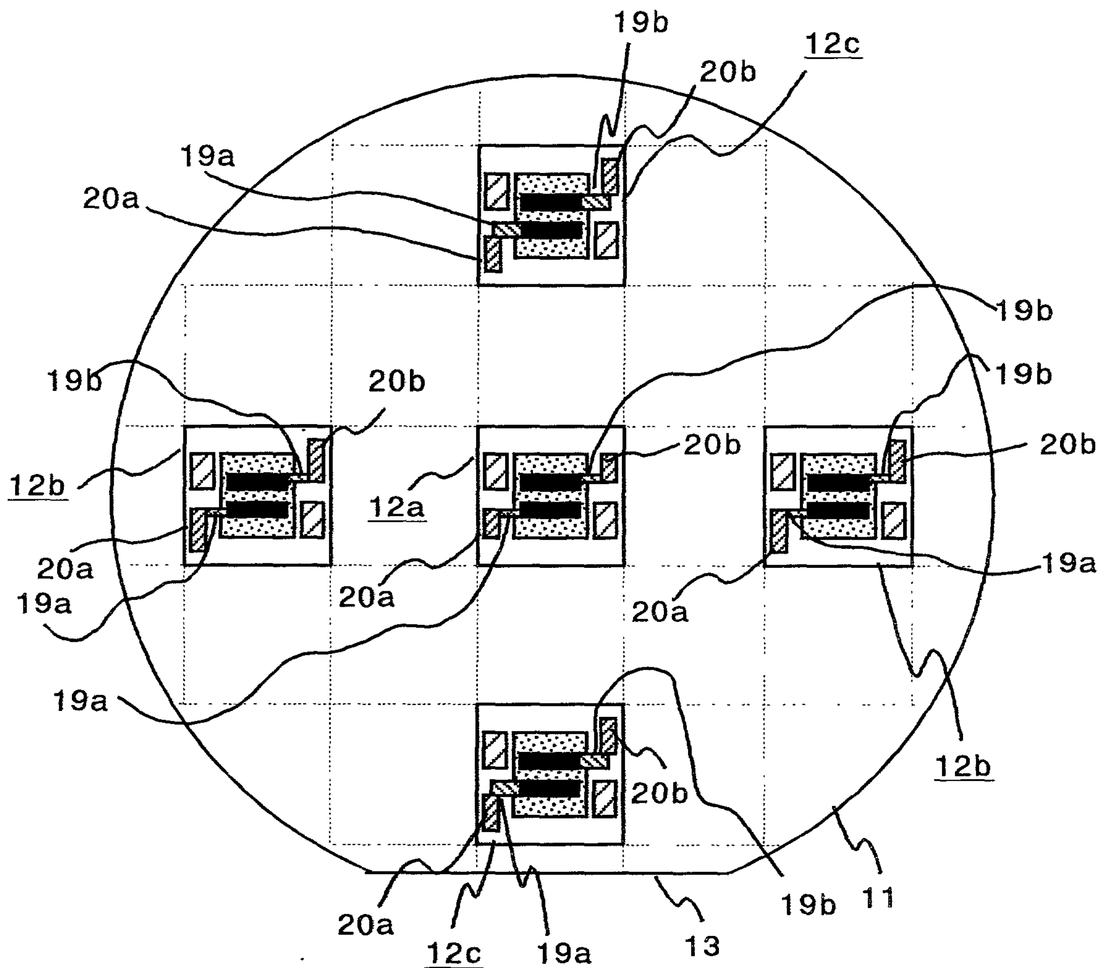
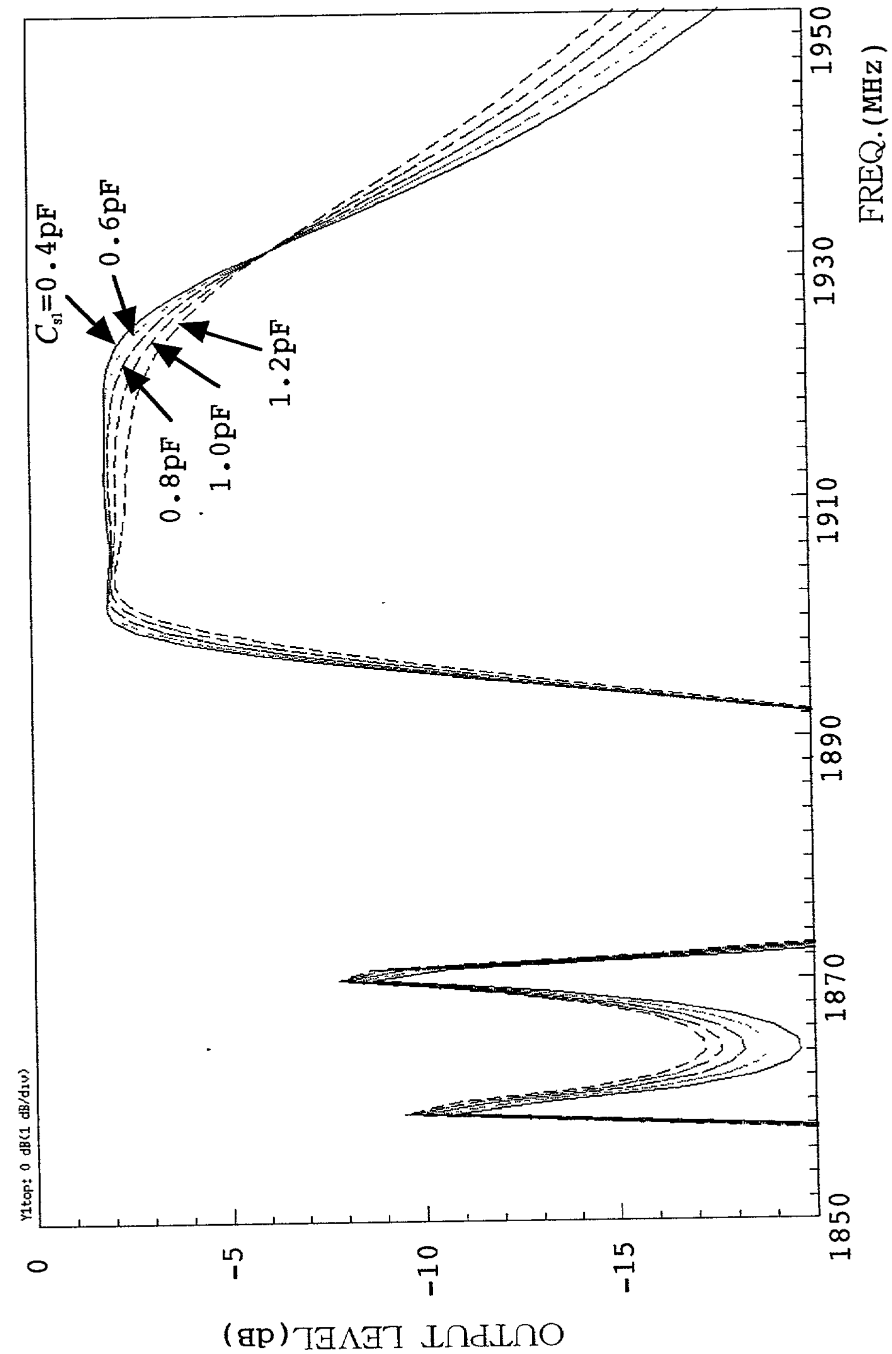
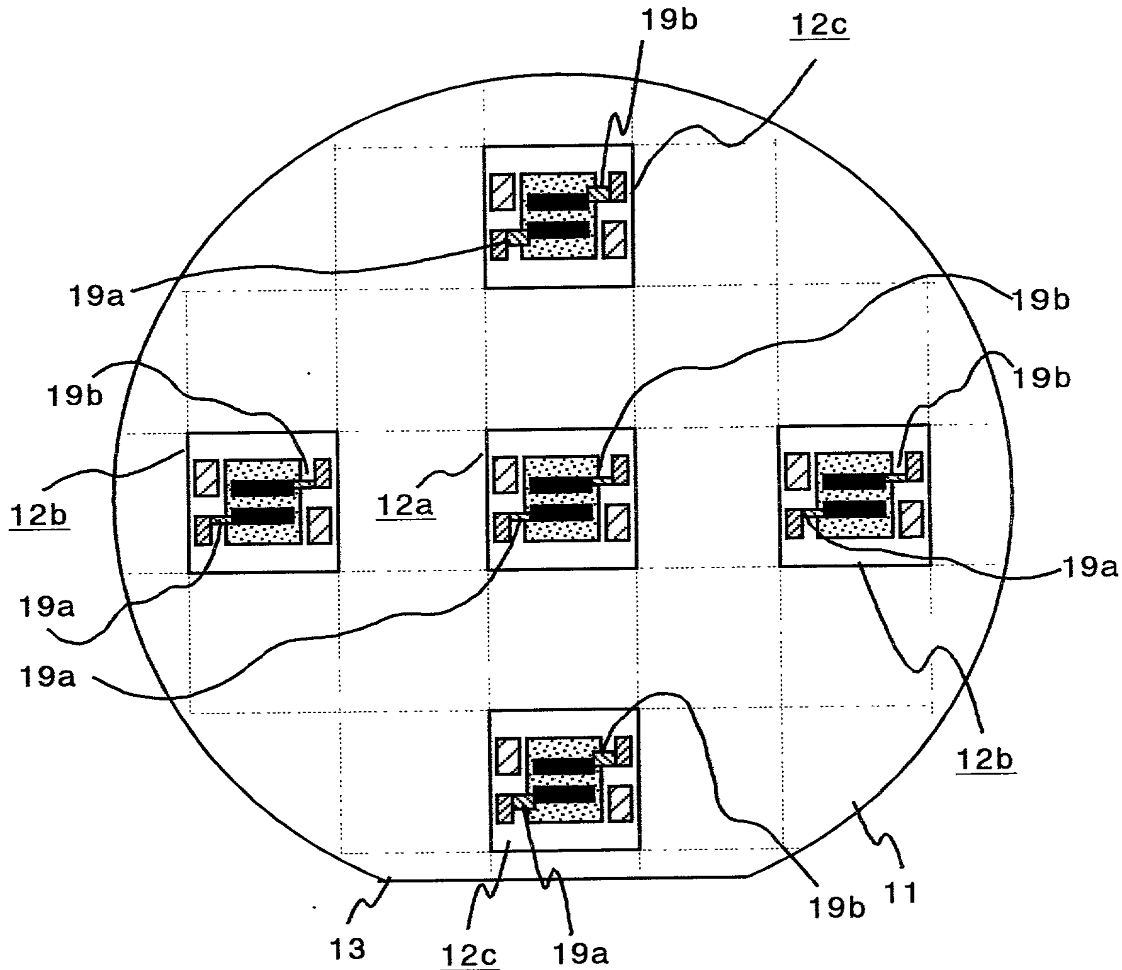

19b
12c
20b
19a
20a
19b
19b
19b
20b
20b
20b
12b
12a
20a
19a
20a
20a
19a
19a
19a
12b
20b
20a
12c
19a
13
19b
11

Fig.16



Y1top: 0 dB(1 dB/div)
C_{s1}=0.4pF
0.6pF
0.8pF
1.0pF
1.2pF
0
-5
-10
-15
OUTPUT LEVEL(dB)
1850
1870
1890
1910
1930
1950
FREQ.(MHz)

Fig.17



09/202070

Fig.18

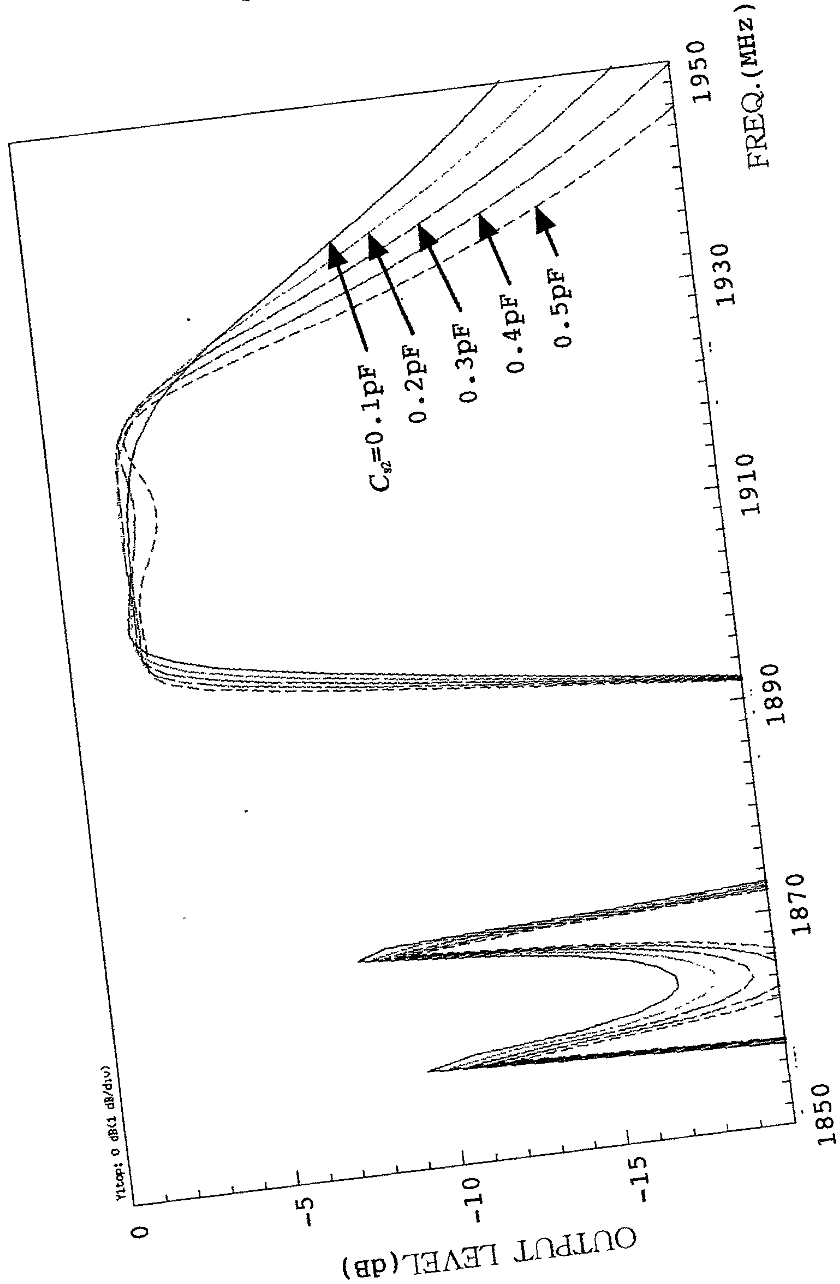


Fig.19

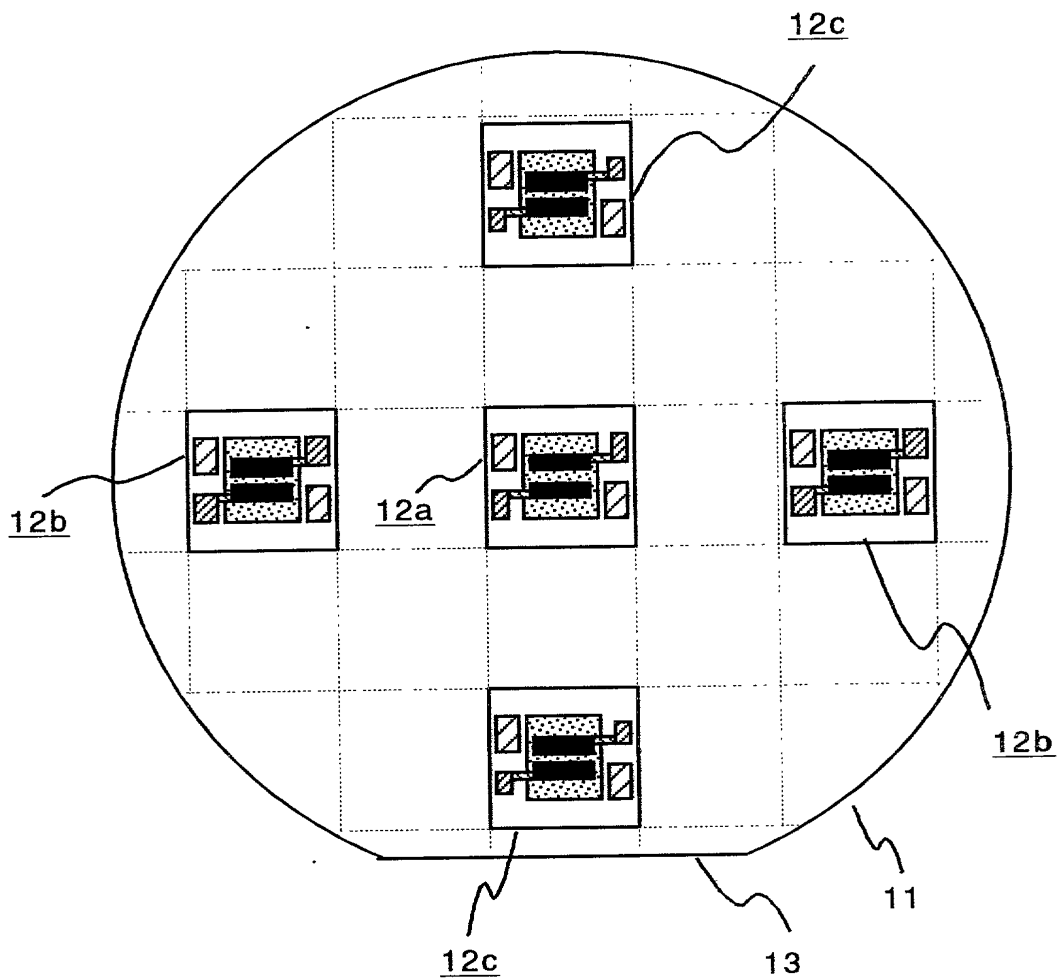
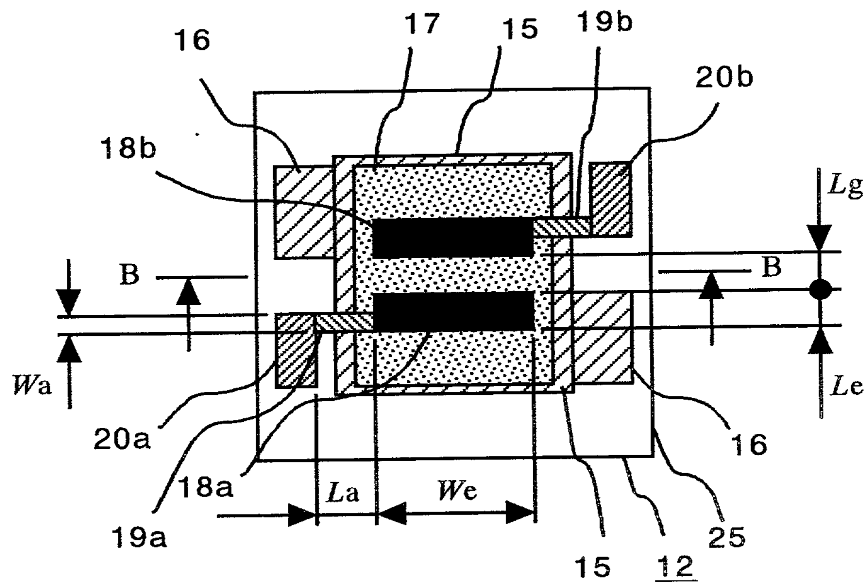
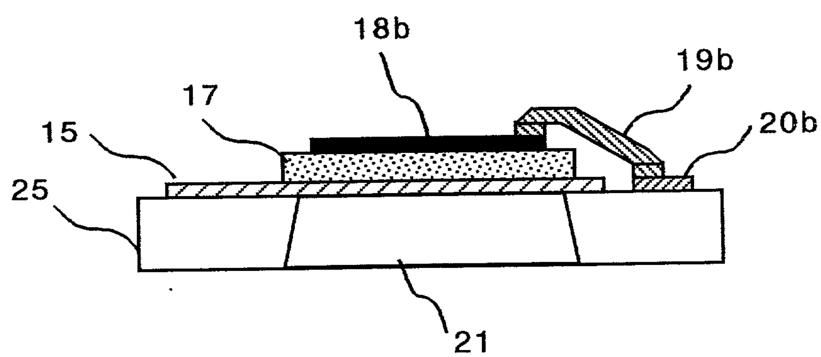


Fig.20



16
17
15
19b
20b
18b
Lg
B
B
Wa
Le
20a
16
18a
La
We
19a
25
15
12

Fig.21



18b
19b
17
20b
15
25
21

Fig.22

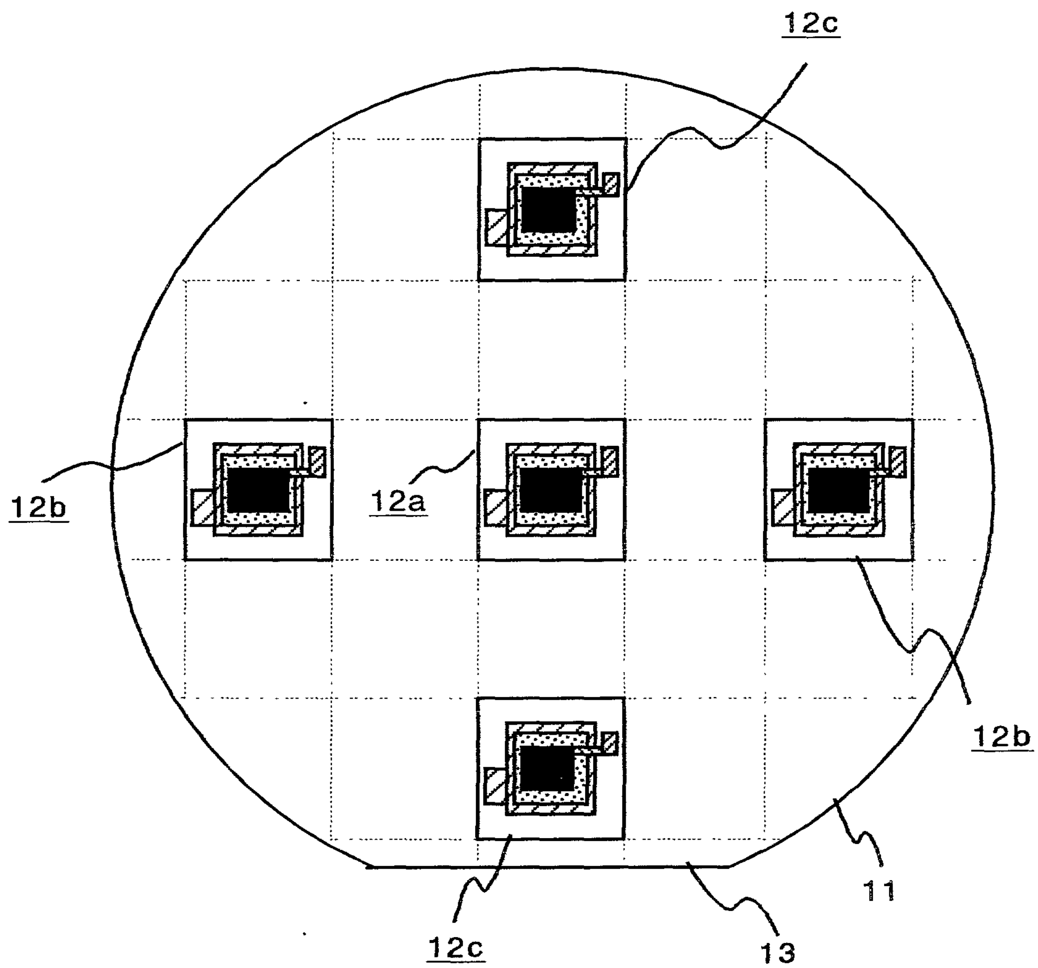


Fig.23

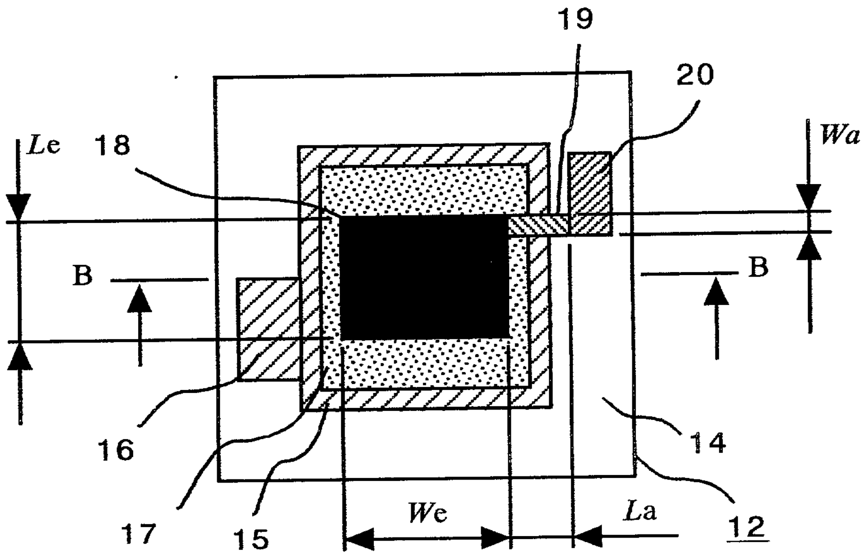


Fig.24

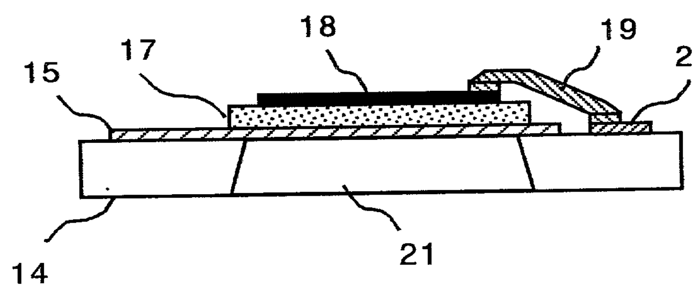


Fig.25

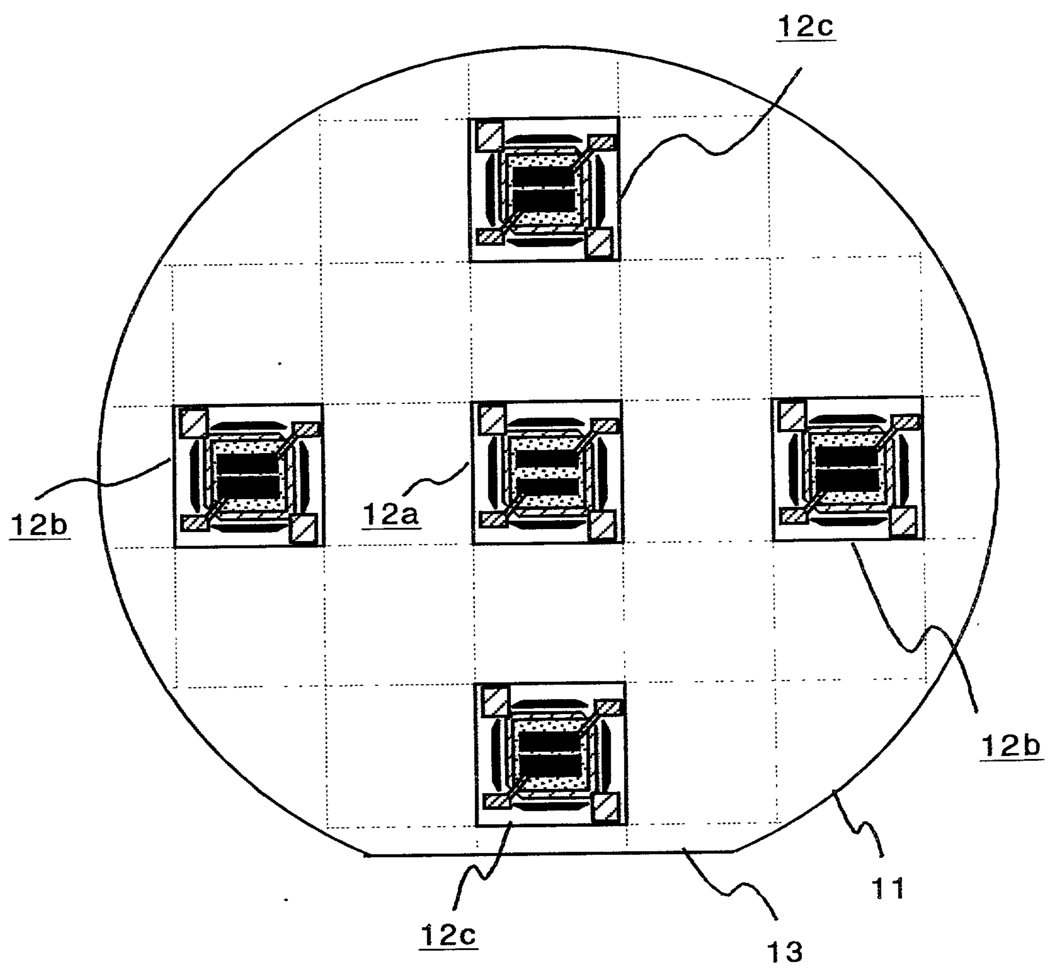


Fig.26

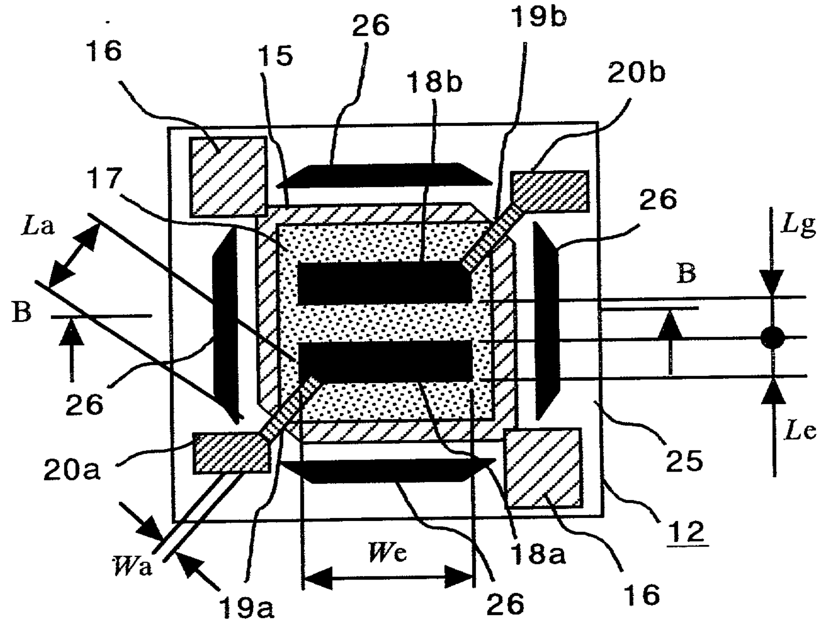

16
15
26
18b
19b
20b
17
26
La
Lg
B
B
26
26
20a
25
Le
12
We
Wa
19a
26
18a
16

Fig.27

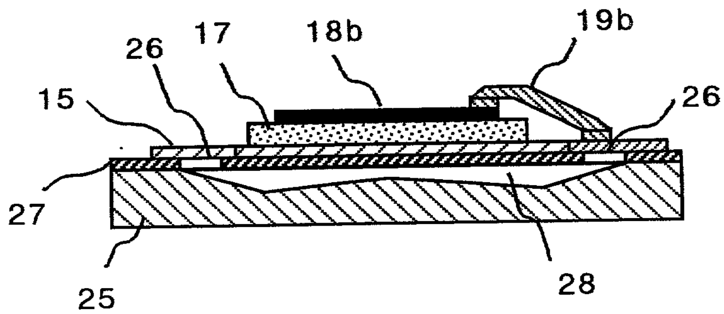

26
17
18b
19b
15
26
27
25
28

Fig.28

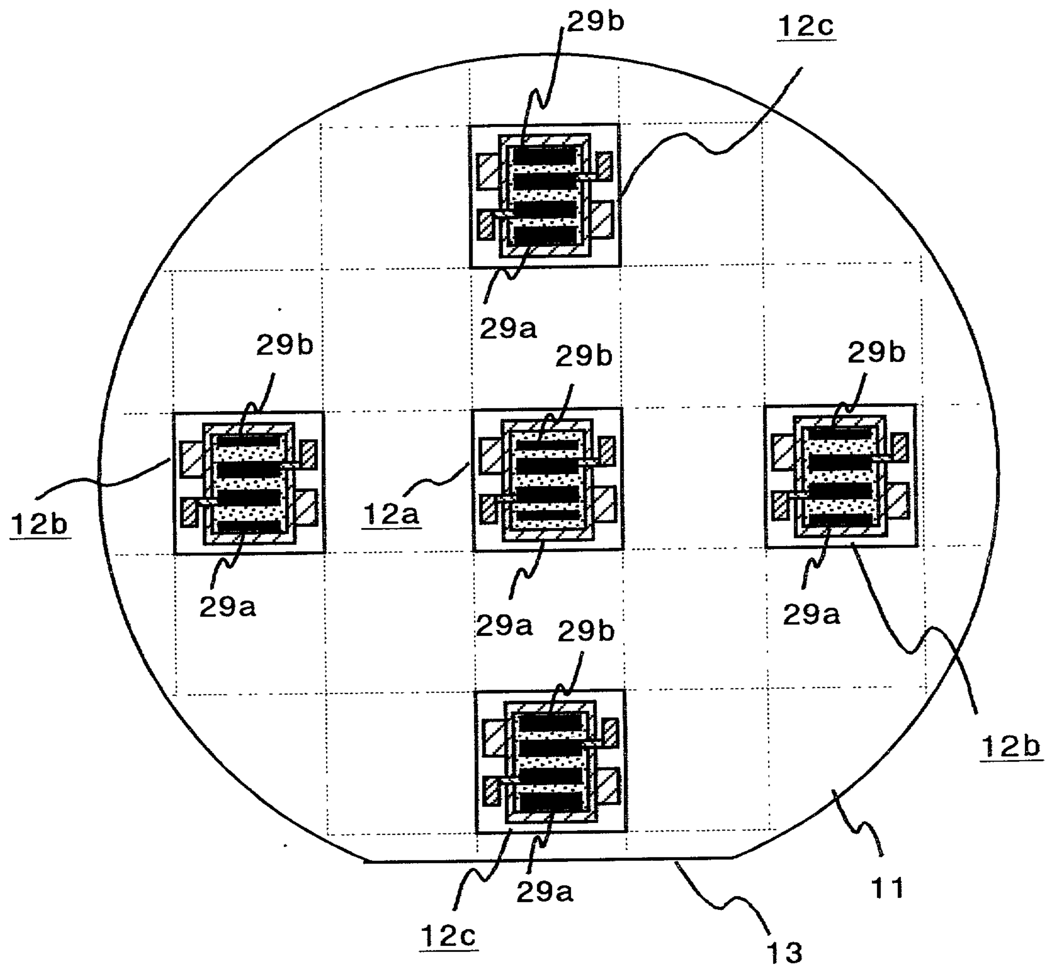


Fig.29

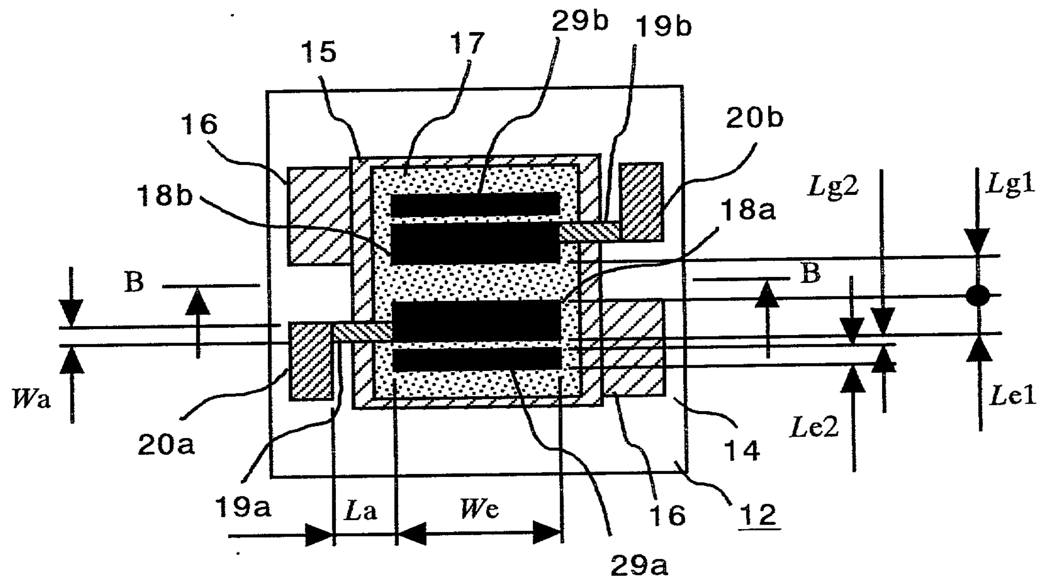

15
17
29b
19b
16
20b
18b
18a
Lg2
Lg1
B
B
Wa
20a
19a
La
We
16
14
Le2
Le1
12
29a

Fig.30

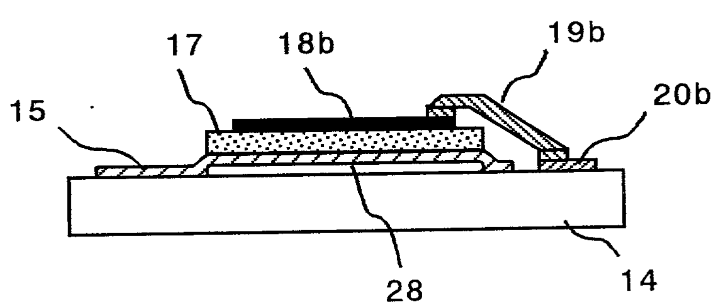

17
18b
19b
15
20b
28
14

Fig.31

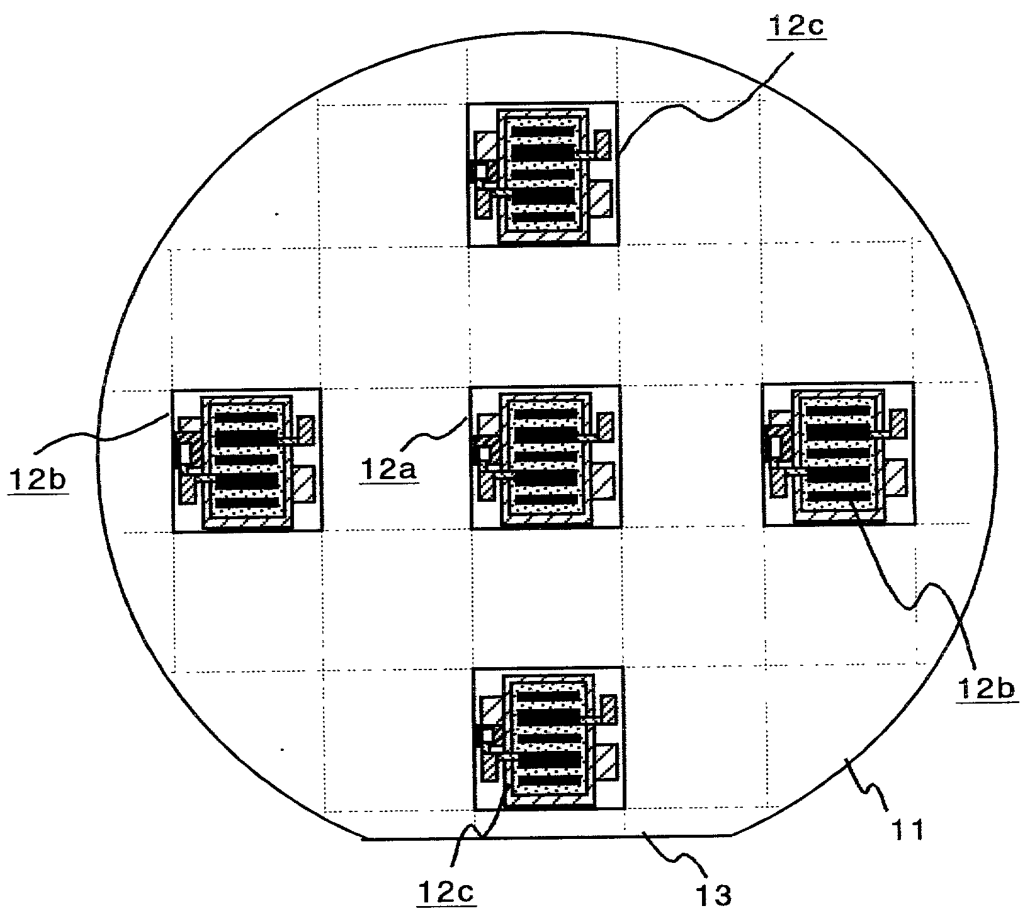
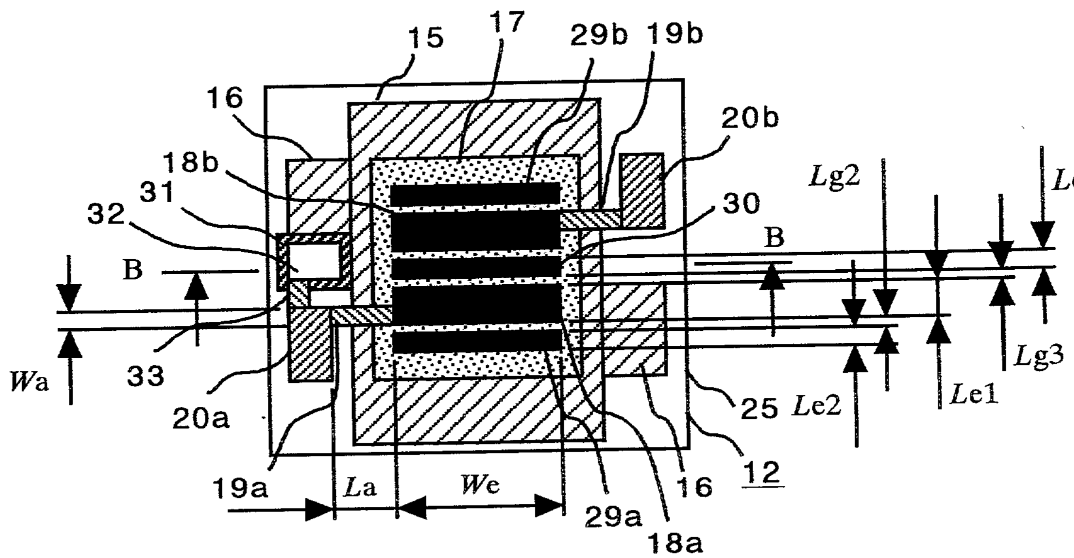


Fig.32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17
29b
19b
16
20b
18b
31
32
Lg2
Le3
30
B
B
33
Wa
20a
25
Le2
Le1
Lg3
19a
La
We
29a
16
12
18a

Fig.33

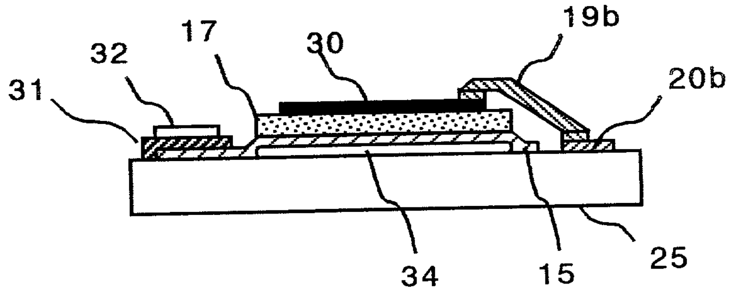

19b
17
30
32
20b
31
34
15
25

Fig.34

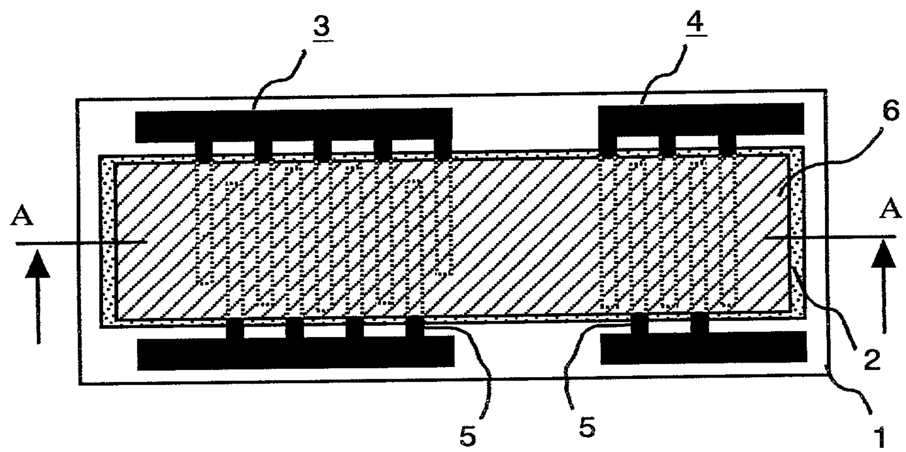


Fig.35

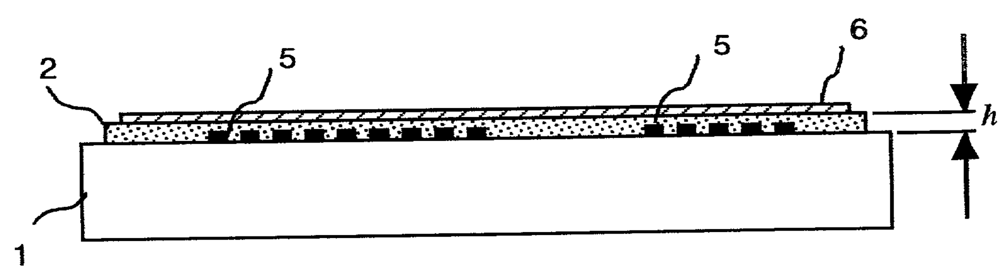


Fig.36

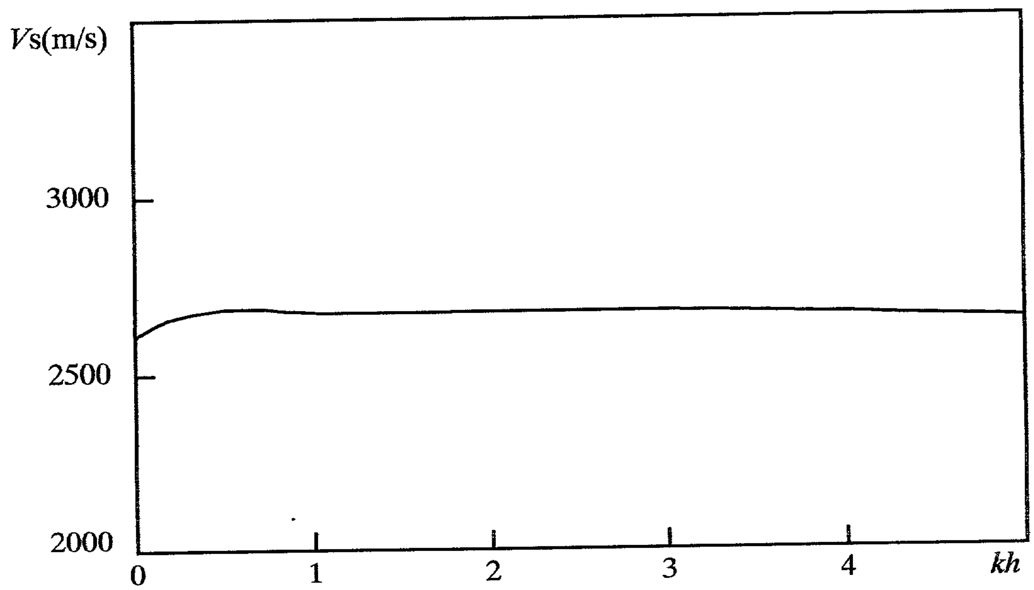
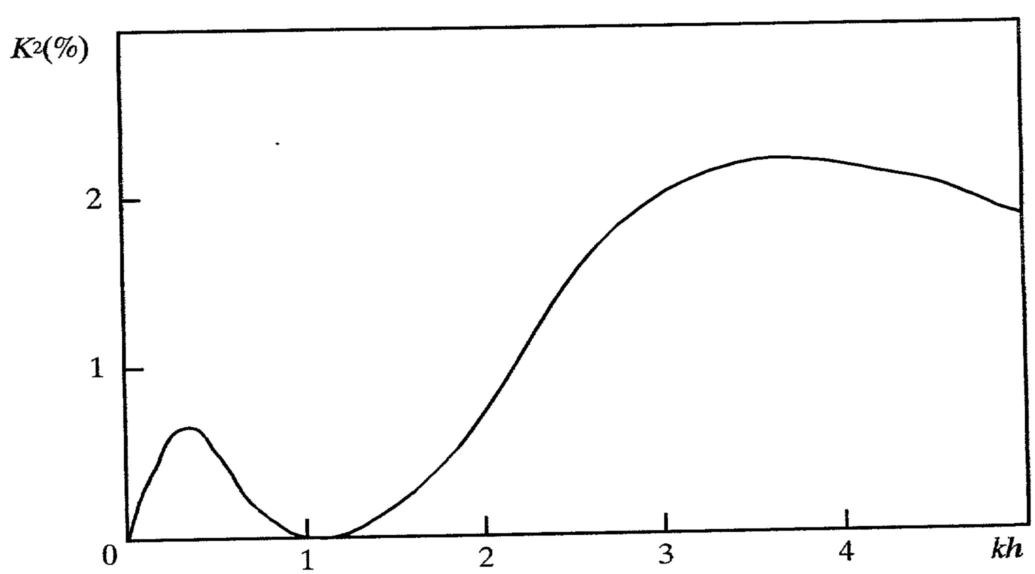


Fig.37



09/202070

Fig.38

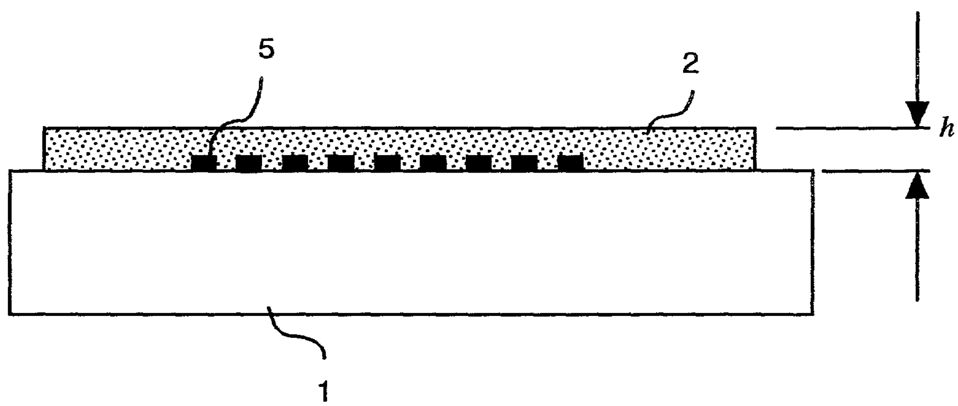


Fig.39

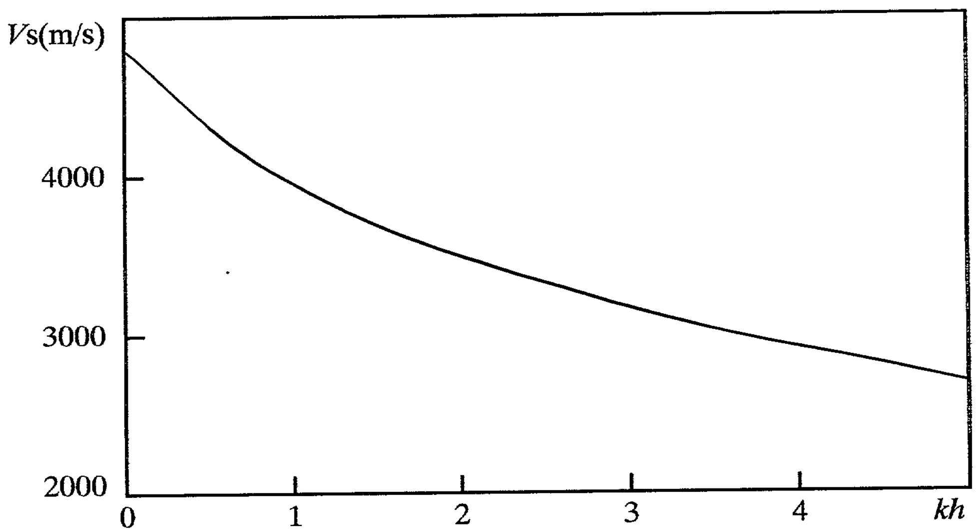


Fig.40

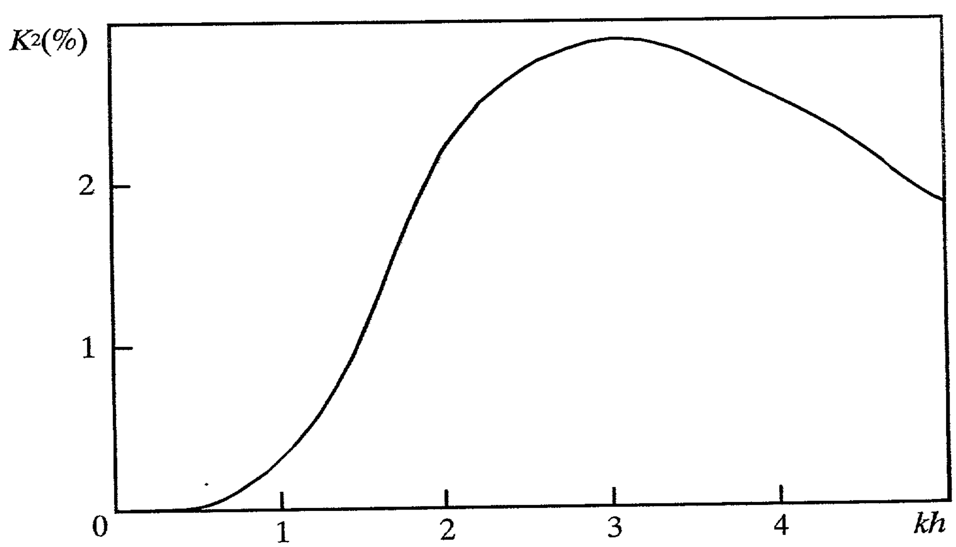


Fig.41

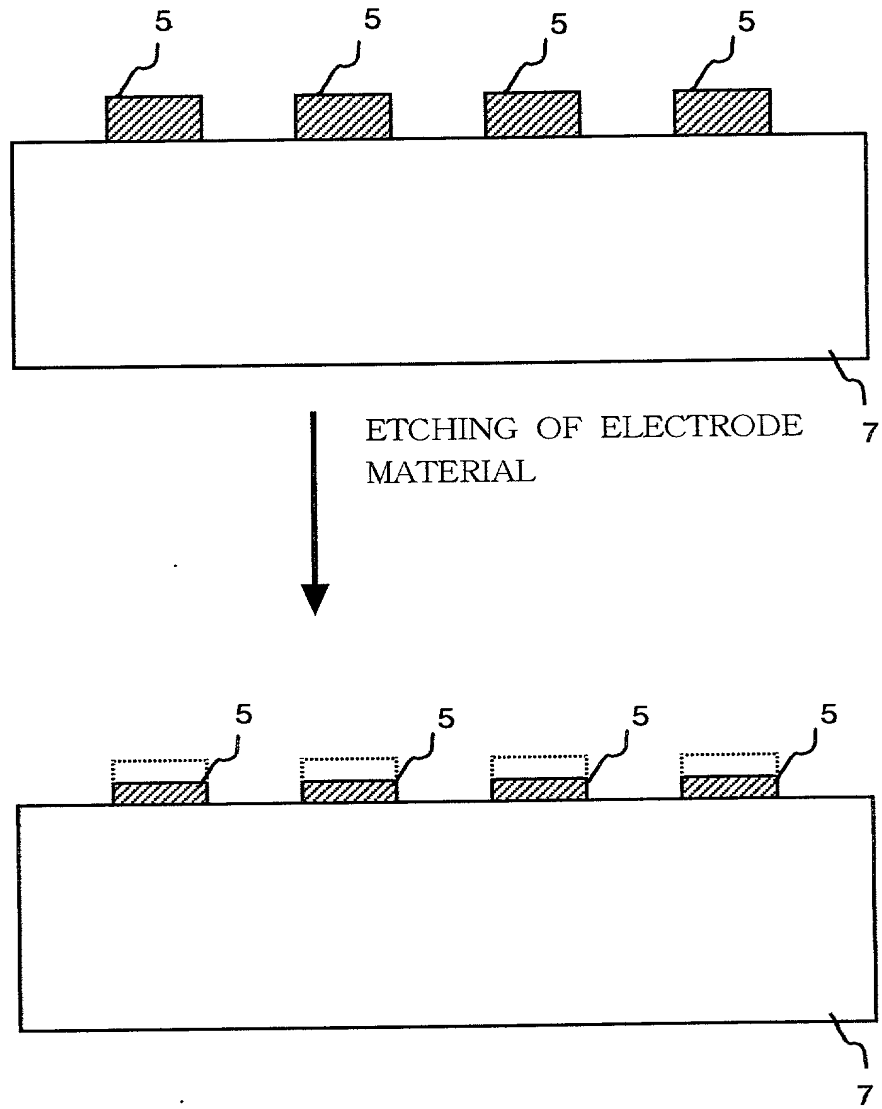


Fig.42

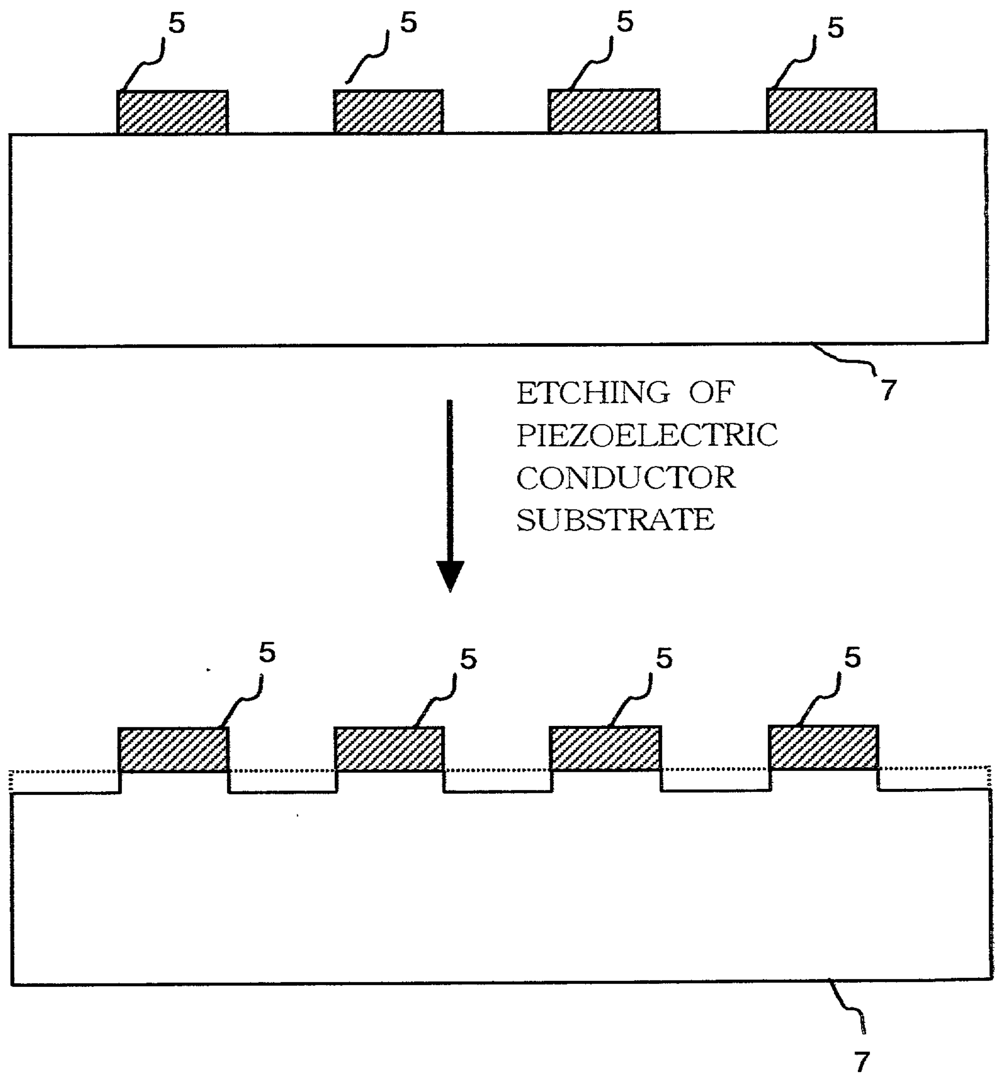

5
5
5
5
7
ETCHING OF
PIEZOELECTRIC
CONDUCTOR
SUBSTRATE
5
5
5
5
7

Fig.43

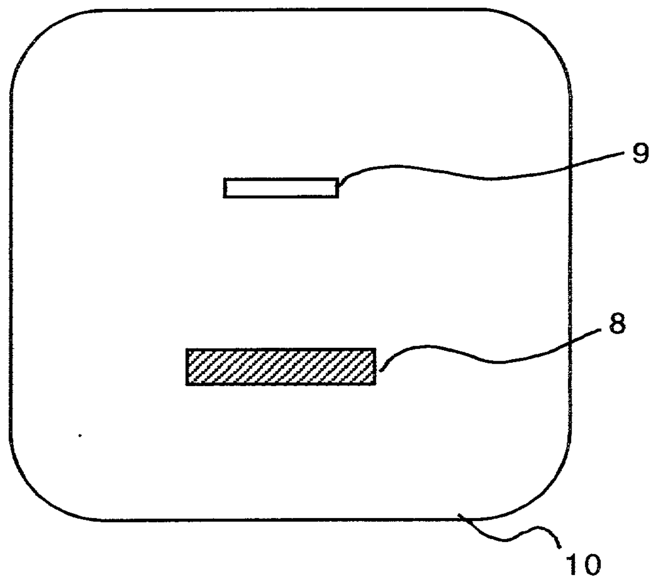
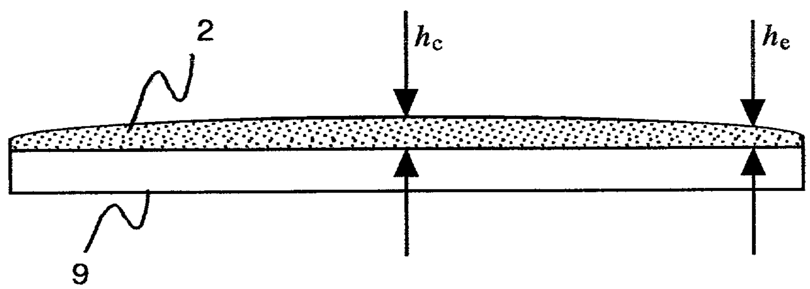


Fig.44



PTO/SB/106 (8-96)
Approved for use through 9/30/98. OMB 0651-0032
Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Declaration and Power of Attorney for Patent Application

特許出願宣告書及び委任状

Japanese Language Declaration

日本語宣告書

下記の氏名の発明者として、私は以下の通り宣言します。

As a below named inventor, I hereby declare that:

私の住所、私書箱、国籍は下記の私の氏名の後に記載された通りです。

My residence, post office address and citizenship are as stated next to my name.

下記の名称の発明に関して請求範囲に記載され、特許出願している発明内容について、私が最初かつ唯一の発明者（下記の氏名が一つの場合）もしくは最初かつ共同発明者であると（下記の名称が複数の場合）信じています。

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) or the subject matter which is claimed and for which a patent is sought on the invention entitled

Film acoustic wave device and its manufacturing method and circuit device

上記発明の明細書（下記の欄でｘ印がついていない場合は本書に添付）は、

the specification of which is attached hereto unless the following box is checked:

☐ _月_日に提出され、米国出願番号または特許協定条約国際出願番号を________とし、（該当する場合）________に訂正されました。

☑ was filed on 24/April/1997 as United States Application Number or PCT International Application Number PCT/JP97/01442 and was amended on ________ (if applicable).

私は、特許請求範囲を含む上記訂正後の明細書を検討し、内容を理解していることをここに表明します。

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

私は、連邦規則法典第３７編第１条５６項に定義されるとおり、特許資格の有無について重要な情報を開示する義務があることを認めます。

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

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Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Japanese Language Declaration
(日本語宣告書)

私は、米国法典第３５編１１９条(a)-(d)項又は３６５条(b)項に基づき下記の、米国以外の国の少なくとも一ヶ国を指定している特許協力条約３６５(a)項に基づく国際出願、又は外国での特許出願もしくは発明者証の出願についての外国優先権をここに主張するとともに、優先権を主張している、本出願の前に出願された特許または発明者証の外国出願を以下に、枠内をマークすることで、示しています。

I hereby claim foreign priority under Title 35, United States Code, Section 119 (a)-(d) or 365(b) of any foreign application(s) for patent or Inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or Inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)
外国での先行出願

Priority Not Claimed
優先権主張なし

Number (番号) ____ Country (国名) ____ Day/Month/Year Filed (出願の年月日) ____ ☐

Number (番号) ____ Country (国名) ____ Day/Month/Year Filed (出願の年月日) ____ ☐

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I hereby claim the benefit under Title 35, United States Code, Section 119 (e) of any United States provisional application(s) listed below

Application No (出願番号) ____ Filing Date (出願日) ____

Application No. (出願番号) ____ Filing Date (出願日) ____

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I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s), or 365(c) of any PCT international application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of application.

Application No (出願番号) ____ Filing Date (出願日) ____ Status : Patented, Pending, Abandoned(現況：特許許可済、係属中、放棄済) ____

私は、私自身の知識に基づいて本宣告書中で私が行う表明が真実であり、かつ私の入手した情報と私の信じるところに基づく表明が全て真実であると信じていること、さらに故意になされた虚偽の表明及びそれと同等の行為は米国法典第１８編第１００１条に基づき、罰金または拘禁、もしくはその両方により処罰されること、そしてそのような故意による虚偽の声明を行えば、出願した、又は既に許可された特許の有効性が失われることを認識し、よってここに上記のごとく宣誓を致します。

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Japanese Language Declaration
（日本語宣告書）

委任状： 私は下記の発明者として、本出願に関する一切の手続きを米特許商標局に対して遂行する弁理士または代理人として、下記の者を指名いたします。（弁理士、または代理人の氏名及び登録番号を明記のこと）

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith (*list name and registration number*)

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RAYMOND C STEWART (Reg.No. 21,066)	BERNARD L SWEENEY (Reg.No. 24,448)	LEONARD R. SVENSSON (Reg.No 30,330)	ANDREW F. REISH (Reg No 33,443)
JOSEPH A KOLASCH (Reg No 22,463)	MICHAEL K MUTTER (Reg.No 29,680)	TERRY L CLARK (Reg.No 32,644)	JOE M MUNCY (Reg.No. 32,334)
ANTHONY L BIRCH (Reg.No 26,122)	CHARLES GORENSTEIN (Reg No. 29,271)	ANDREW D MEIKLE (Reg No 32,868)	C JOSEPH FARACI (Reg No 32,350)

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唯一のまたは第１の発明者名 1-00	Full Name of sole or first Inventor Shusou Wadaka
同発明者の署名 日付	First inventor's signature Date Shusou Wadaka Jun 24, 1998
住所	Residence Tokyo, Japan JPX
国籍	Citizenship Japan
私書箱	Post Office Address c/o Mitsubishi Denki Kabushiki Kaisha 2-3, Marunouchi 2-chome, Chiyoda-ku, Tokyo 100-8310 Japan
第２共同発明者の氏名 2-00	Full Name of second joint inventor Koichiro Misu
第２発明者の署名 日付	Second inventor's signature Date Koichiro Misu Jun 24, 1998
住所	Residence Tokyo, Japan JPX
国籍	Citizenship Japan
私書箱	Post Office Address c/o Mitsubishi Denki Kabushiki Kaisha 2-3, Marunouchi 2-chome, Chiyoda-ku, Tokyo 100-8310 Japan

（第三以降の共同発明者についても同様に記載し、署名をすること）

(Supply similar information and signature for third and subsequent joint inventors.)

第3共同発明者の氏名	Full Name of third joint inventor 3-00 Tsutomu Nagatsuka
第3発明者の署名 日付	Third inventor's signature Date Tsutomu Nagatsuka June 24, 1998
住所	Residence Tokyo, Japan JPX
国籍	Citizenship Japan
私書箱	Post Office Address c/o Mitsubishi Denki Kabushiki Kaisha 2-3, Marunouchi 2-chome, Chiyoda-ku, Tokyo 100-8310 Japan
第4共同発明者の氏名	Full Name of fourth joint inventor 4-00 Tomonori Kimura
第4発明者の署名 日付	Fourth inventor's signature Date Tomonori KIMURA June 24, 1998
住所	Residence Tokyo, Japan JPX
国籍	Citizenship Japan
私書箱	Post Office Address c/o Mitsubishi Denki Kabushiki Kaisha 2-3, Marunouchi 2-chome, Chiyoda-ku, Tokyo 100-8310 Japan
第5共同発明者の氏名	Full Name of fifth joint inventor 5-00 Shumpei Kameyama
第5発明者の署名 日付	Fifth inventor's signature Date Shumpei Kameyama June 24, 1998
住所	Residence Tokyo, Japan JPX
国籍	Citizenship Japan
私書箱	Post Office Address c/o Mitsubishi Denki Kabushiki Kaisha 2-3, Marunouchi 2-chome, Chiyoda-ku, Tokyo 100-8310 Japan
第6共同発明者の氏名	Full Name of sixth joint inventor
第6発明者の署名 日付	Sixth inventor's signature Date
住所	Residence
国籍	Citizenship
私書箱	Post Office Address
第7共同発明者の氏名	Full Name of seventh joint inventor
第7発明者の署名 日付	Seventh inventor's signature Date
住所	Residence
国籍	Citizenship
私書箱	Post Office Address